

# OPTIMIZING SURFACE ROUGHNESS IN TURNING OPERATION USING TAGUCHI TECHNIQUE AND ANOVA

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## Abstract

The objective of this paper is to obtain an optimal setting of Turning parameters (Cutting speed, Feed and Depth of Cut) which results in an optimal value of Surface Roughness while machining Al 6351-T6 alloy with Uncoated Carbide Inserts. Several statistical modelling techniques have been used to generate models including Genetic Algorithm, Response Surface Methodology. In our study, an attempt has been made to generate a model to predict Surface Roughness using Regression Technique. Also an attempt has been made to optimize the process parameters using Taguchi Technique. S/N ratio and ANOVA analysis were also performed to obtain significant factors influencing Surface Roughness.

**Keywords:** Turning operation, Surface Roughness, Mathematical Model, ANOVA, Taguchi Technique.

## 1. Introduction

From past so many years it has been recognized that conditions during machining such as Cutting speed, Feed and Depth of Cut (DOC) should be selected to optimize the economics of machining operations. Manufacturing industries in developing countries suffer from a major drawback of not running the machine at their optimal operating conditions. Machining industries are dependent on the experience and skills of the machine tool operators for optimal selection of cutting conditions. In machining industries the practice of using hand book based conservative cutting conditions are in progress at the process planning level. The disadvantage of this unscientific practice is the decrease in productivity due to sub optimal use of machining capability. The literature survey has revealed that several researchers attempted to calculate the optimal cutting conditions in turning operations. Armarego and Brown used the concept of maxima / minima of differential calculus to optimize machining variable in turning operation <sup>[1]</sup>. Brewer and Rueda have developed different monograms which assist in the selection of optimum conditions <sup>[2]</sup>. Some of the other techniques which have been used to optimize the machining parameters include goal programming <sup>[3]</sup> and geometrical programming <sup>[4]</sup>. Now a days more attention is given to accuracy and Surface Roughness of the product in the industries. Surface roughness is the most important criteria in determining the machinability of the material. Surface Roughness and dimensional accuracy are the major factors needed to predict the machining performances of any machining operation <sup>[5]</sup>. Most of the Surface Roughness prediction models are empirical and they are generally based on experiments conducted in the laboratory. Also it is difficult in practice, to keep all factors under control as required to obtain the reproducible results <sup>[6]</sup>. Optimization of machining parameters increases the utility for machining economics and also increases the product quality to greater extent <sup>[7]</sup>.

Taguchi has proposed off line for quality improvement in place of an attempt to inspect quality in the product on the product line. He observed that no amount of an inspection can put quality back into the product but it merely treats a symptom. Taguchi has recommended three stage process to achieve the desirable product quality by design. They are 1). System Design 2). Parameter Design and 3). Tolerance Design. System design helps to identify the working levels of the design parameters. Parameter design determines the parameter levels that

produce the best performance of the product or process under study. The optimal condition is selected so that influence of noise factors (uncontrollable factors) causes minimum variation to study performances. The orthogonal arrays, variance and signal to noise analysis are the essential tools of parameter design. Tolerance design is used to fine tune the results of parameter design by tightening the tolerance of the parameter with the significant influence on the product.

In this paper Taguchi DOE (Design of Experiments) approach is used to analyze the effect of Turning process parameters that is Cutting Speed, Feed and Depth of Cut on Surface Roughness. While machining Al 6351-T6 alloy using Uncoated Carbide Inserts and to obtain an optimal setting of these parameters that may result in optimizing Surface Roughness.

## 2. Taguchi technique

Genichi Taguchi is a Japanese Engineer who has been active in the improvement of Japan's industrial product and processes since the late 1940s. He has developed both philosophy and methodology for the process or product quality improvement that depends mainly on statistical concepts and tools, especially statistically designed experiments. Many Japanese firms achieved great success by applying his methods. Taguchi has received some of the Japan's most prestigious awards for quality achievement, including the Deming Prize<sup>[8]</sup>. During the year 1986, he received the most prestigious award from the International Technology Institute- The W.F.Rockwell Medal for excellence in Technology. His major contribution is that he has combined engineering and statistical techniques to achieve rapid improvements in reducing the cost and increasing the quality level by optimizing product design and manufacturing processes. During 1983, Taguchi associated with top companies and institutes of USA (Ford motor company, XEROX, AT&T, Bell laboratories etc), Taguchi techniques are called as Radial approach to quality, experimental design and engineering<sup>[9]</sup>. Taguchi technique refers to the Parameter Design, Tolerance Design, Quality Loss Function, Design of Experiments using Orthogonal Arrays and Methodology applied to evaluate measuring systems<sup>[8]</sup>.

Pignatiello<sup>[10]</sup> has identified two different aspects of Taguchi technique 1). The strategy of Taguchi. 2). Tactics of Taguchi. Taguchi strategy is the conceptual frame work for planning a process or product design experiment. Taguchi tactics refer to the collection of specific techniques used by Taguchi.

Taguchi has addressed Design, Engineering (offline) as well as Manufacturing (online) quality. This concept differentiates Taguchi technique from Statistical Process Control (SPC) which is purely an online quality control technique<sup>[10, 11]</sup>. Taguchi ideas can be reduced into two fundamental concepts 1). Quality losses should be defined as deviation from target, not conformance to arbitrary specifications.<sup>[11]</sup> 2). To achieve high system quality levels economically requires quality to be designed into product. Quality is designed, not manufactured, into the product.<sup>[12, 13]</sup>

Taguchi techniques represent a new philosophy.<sup>[14]</sup> Quality is measured by the deviation of a functional characteristic from its target value. Noises (uncontrollable factors) will cause such deviations which results in loss of Quality. Taguchi techniques seek to remove the effect of Noises. The most important part of the Taguchi technique is quality loss function<sup>[15]</sup>. Taguchi has found that a quadratic function (parabola) approximates the behavior of loss in many cases<sup>[9]</sup>. when the quality characteristic of interest is to be maximized or minimized, the loss function will become a half parabola<sup>[16]</sup>. Loss occurs not only when the product is outside its specification but also when product falls within its specification<sup>[17]</sup>. Taguchi has recommended signal to noise ratio (S/N ratio) as performance statistics<sup>[18]</sup>. Signal refers to the change in quality characteristics of a product under investigation in response to a factor introduced in the experimental design. Noise refers to the effect of external factors (uncontrollable parameters) on the outcome of the quality characteristics<sup>[19]</sup>.

## 3. Turning process parameters

The process parameters that are affecting the characteristics of turned parts are 1).Cutting Tool parameters-Tool geometry and Tool material. 2).Work piece related parameters –Hardness, Metallography. 3).Cutting parameters –Cutting Speed, Feed, Depth of Cut. 4).Environmental parameters-Dry cutting, Wet cutting<sup>[20,21,22]</sup>.

The following process parameters were selected for the present work: Cutting speed-(A), Feed-(B), Depth of Cut-(C), Tool Material- Uncoated Carbide Inserts, Work Material- Al 6351-T6 alloy, Environment-Dry Cutting. The ranges of the selected process parameters were ascertained by conducting preliminary experiments using one variable at a time approach<sup>[23]</sup>.

The work material used for this experimentation is Al 6351- T6 alloy. This material is widely used in the aerospace industry.

Table 1: Chemical composition of Al 6351- T6

Element	Ti	Cu	Fe	Mg	Zn	Si	Mn	Others	Balance
Wt%	0.2	0.1	0.5	0.4	0.2	0.7	0.4	0.15	Al

Table 2: Mechanical Properties of Al 6351- T6

<b>Brinell Hardness Number (BHN)</b>	95
<b>Density</b>	$2.8 \times 10^3 \text{ kg/m}^3$
<b>% Elongation</b>	20
<b>Tensile Strength, Ultimate</b>	250 MPa
<b>Yield Strength</b>	150 MPa
<b>Poissons Ratio</b>	0.330
<b>Fatigue Strength</b>	90 MPa
<b>Shear Strength</b>	200 Mpa

Table 3: Experimental Conditions

<b>Work piece Material</b>	Al 6351- T6
<b>Length of the work piece</b>	75 mm
<b>Diameter of the work piece</b>	25.3 mm
<b>Lathe Used</b>	CNC Lathe (ULTRALYNX-Pride-FANUC)
<b>Inserts Used</b>	Uncoated Carbide Insert (KORLOY Make)
<b>Insert Designation</b>	TNMG 16 04 08 (ISO Designation)
<b>Tool holder</b>	MTJNL 25 * 25 * H 16 (ISO Designation)
<b>Measuring Instrument</b>	Profilometer (Talysurf), Mitutoyo SJ-201P (for measuring Surface Roughness)
<b>Environment</b>	DRY

Table 4: Process parameters with their values at 3 levels

Process Parameters	Parameter Designation	Levels		
		L1	L2	L3
<b>Speed (rpm)</b>	A	500	1000	1500
<b>Feed (mm/rev)</b>	B	0.1	0.4	0.7
<b>Depth of Cut (mm)</b>	C	0.2	0.5	0.8

The experimental layout was developed based on Taguchi's Orthogonal Array Experimentation Technique. An  $L_9$  Orthogonal Array Experimental layout was selected to satisfy the minimum number of experiment conditions for the factors and levels presented in Table 5.

Table 5: Factors, Levels and Degrees of Freedom

Factor Code	Factor	No of Levels	Degree of Freedom
<b>A</b>	Speed	3	2
<b>B</b>	Feed	3	2
<b>C</b>	Depth of Cut	3	2
Total degrees of freedom			6
Minimum number of Experiments			7

Table 6: Standard L9 Orthogonal Array

Trial No.	Speed (rpm)	Feed (mm/rev)	DOC (mm)
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 7: Standard L9 Array with Observations

Trial No.	Speed (rpm)	Feed (mm/rev)	DOC (mm)	Ra -1	Ra -2	Ra -3	Ra (Avg) ( $\mu\text{m}$ )
1	500	0.1	0.2	0.85	0.82	0.97	<b>0.87</b>
2	500	0.4	0.5	2.61	2.54	2.4	<b>2.56</b>
3	500	0.7	0.8	0.73	0.74	0.6	<b>0.69</b>
4	1000	0.1	0.5	3.56	3.85	3.66	<b>3.69</b>
5	1000	0.4	0.8	4.07	3.06	3.46	<b>3.45</b>
6	1000	0.7	0.2	2.7	2.87	2.96	<b>2.78</b>
7	1500	0.1	0.8	3.88	3.54	3.43	<b>3.60</b>
8	1500	0.4	0.2	3.91	3.61	3.73	<b>3.66</b>
9	1500	0.7	0.5	1.32	1.21	1.41	<b>1.24</b>

Table 1 shows the chemical composition of the test specimen i.e., Al 6351- T6. Table 2 shows the mechanical properties of the test specimen. Table 3 shows the experimental conditions followed during the present experiment. Table 4 shows process parameters with their values at 3 levels. Table 5 shows the Factors, Levels,

Degrees of Freedom and Total Minimum number of Experiments to be conducted. Table 6 shows the standard L9 Orthogonal Array (OA). Table 7 shows the L9 OA with observed values for each parameter.

**3.1 Regression Model for Surface Roughness:**

Using Minitab Software the Regression Model has been developed for the above Experiment. The regression equation is

$$Ra (\mu m) = 1.69 + 0.00146 \text{ Speed (rpm)} - 1.92 \text{ Feed (mm/rev)} + 0.24 \text{ DOC (mm)}$$

Table 8: General Linear Model for Surface Roughness Ra

Factor	Type	Levels	Values
Speed	Fixed	3	500, 1000, 1500
Feed	Fixed	3	0.1, 0.4, 0.7
DOC	Fixed	3	0.2, 0.5, 0.8

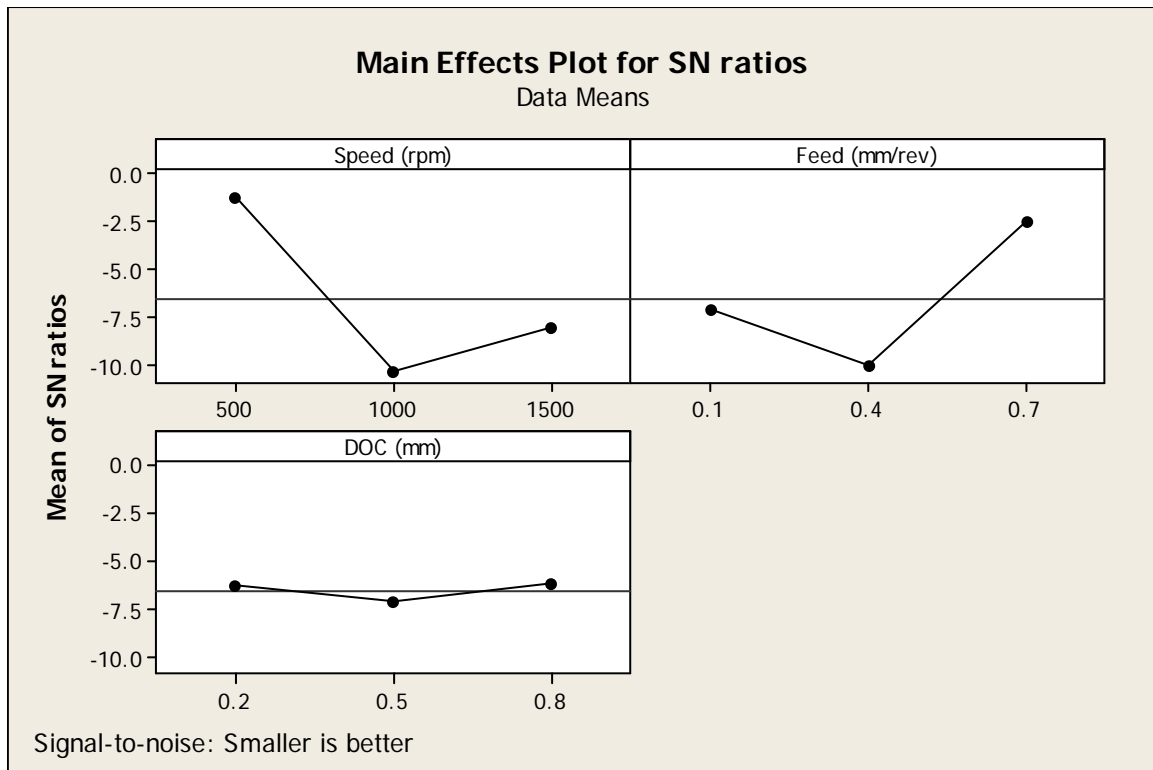
Table 9: Analysis of Variance (ANOVA) for Surface Roughness Ra

Source	DOF	Seq SS	Adj SS	Seq MS	F	P	Rank
Speed	2	6.093	6.093	3.047	2.98	0.251	1
Feed	2	4.309	4.309	2.155	2.11	0.322	2
DOC	2	0.031	0.031	0.016	0.02	0.985	3
Error	2	2.043	2.043	1.021			
Total	8	12.477					

S = 1.01063 R-Sq = 83.63% R-Sq(adj) = 34.51%

Table 10: Response Table for Signal to Noise Ratios  
Smaller is better

Level	Speed (rpm)	Feed (mm/rev)	DOC (mm)
1	-1.244	-7.086	-6.314
2	-10.326	-10.064	-7.125
3	-8.088	-2.509	-6.220
Delta	9.082	7.555	0.905
Rank	1	2	3



Graph 1: S/N ratio values for Surface Roughness

#### 4. Conclusion:

Following are the conclusions drawn based on the test conducted on Al 6351- T6 alloy during Turning operation with Uncoated Carbide Insert.

- i) From the results obtained a Regression Model has been developed for Surface Roughness. From this equation we can predict the value of Surface Roughness if the values of Cutting Speed, Feed and Depth of Cut are known.
- ii) From ANOVA Table 9 and Response Table 10 for Signal to Noise ratios, based on the ranking it can be concluded that Speed has a greater influence on the Surface Roughness followed by Feed. Depth of Cut had least influence on Surface Roughness.
- iii) The validation experiment confirmed that the error occurred was less than 2.0 % between equation and actual value.
- iv) The optimal settings of process parameters for optimal Surface Roughness are: Speed (500 rpm), Feed (0.7 mm/rev), and DOC (0.8 mm).

This research gives us how to use Taguchi's parameter design to obtain optimum condition with lowest cost, minimum number of experiments and Industrial Engineers can use this method. The research can be extended for other materials using Tool Nose Radius, Lubricant, Material Hardness etc as parameters.

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