Analysis and Optimization of Surface Roughness in Turning Operation of Mild Steel using Taguchi Method

Ravi Patel[#1], Ankit Kumar[*2], Jitendra Kumar Verma[#3]

[#1,*2]M.Tech Student,Mechanical Engineering Deptt. Bhabha Institute of Technology, Kanpur Dehat U.P, India

[#3]Assistant Professor,Mechanical Engineering Deptt. Bhabha Institute of Technology, Kanpur Dehat U.P, India

Abstract — *This study was based on optimizing the turning process under different machining parameters by Taguchi method to improve the surface roughness (quality) of the product due to this decreases the machining time, increases the production rate and decreasing the product manufacturing cost. Taguchi optimization methodology is applied to optimize cutting parameters in turning of mild steel with carbide tool under dry cutting condition. The Centre Lathe machine was used for experiments based on the Taguchi design of experiments (DOE) with orthogonal L9 array. The Taguchi method is a important statistical tool, adopted experimentally to analyse the surface roughness by cutting parameters such as cutting speed, feed and depth of cut. The orthogonal array, signal to noise ratio (S/N) and Taguchi method were employed to find minimum surface roughness. From the Experimental result of Taguchi method it is found that Depth of cut is most significant, spindle speed is significant and feed rate is least significant factor effecting surface roughness.*

Keywords — *Lathe machine, Optimization, DOE, Taguchi method, Mild steel, Surface Roughness etc.*

I. Introduction

Surface finish also known as surface texture is the characteristics of a surface [1]. Machining is a most important operation in manufacturing but it is seen from the past year study, it has been recognized that conditions during machining such as Cutting speed, Feed rate 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 [2]. Brewer and Rueda have developed different monograms which assist in the selection of optimum conditions [3]. Some of the other techniques which have been used to optimize the machining parameters include goal programming [4] and geometrical programming [5]. Now a day's 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 machine ability of the material. Surface Roughness and dimensional accuracy are the major factors needed to predict the machining performances of any machining operation [6]. 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 [7]. Optimization of machining parameters increases the utility for machining economics and also increases the product quality to greater extent [8].

In this research Taguchi DOE (Design of Experiments) approach is used to analyze the effect of turning process parameters that is spindle Speed, Feed and Depth of Cut on Surface Roughness. While machining of mild steel using Carbide cutting tool and to obtain an optimal setting of these parameters that may result in optimizing Surface Roughness.

II. Taguchi Method

Taguchi method was developed by Genichi Taguchi. It is a best and powerful statistical method used in various sector like manufacturing sector Maintenance Sector, Research and Development sector etc. Taguchi method is based on mean and variance of the values with two or more noise factors. Steps of Taguchi method for optimization are as follows [9].

1. Identification and evaluation of quality characteristics and process parameters.
2. Identification of number of levels for the process parameters and possible

interactions between the process parameters.
3. Assignment of process parameters to the selected appropriate orthogonal array.
4. Conduction of experiments based on the arrangement of the orthogonal array.
5. Calculation of S/N ratio.
6. Analyze the experimental results using the S/N ratio and ANOVA.
7. Selection of the optimal levels of process parameters.
8. Verification of the optimal process parameters through the confirmation experiment.[10]

Run a confirmatory Experiment. It also helps to predict the difference between predicted value and actual observed value.

A. Orthogonal Array

Arranging experiments under multiple factors are known as the Factorial DOE. This method helps the researchers in determination of the possible combinations of factors and the identification of the best combination and their levels. However in industrial location it is very costly process to run large number of experiments in testing all combinations. The Taguchi approach describe the plans in carrying out experiments and also standardized the design of the experiment along with minimum number of factor combinations that would be required for testing the influence of factors [10].

III. EXPERIMENTAL SETUP AND CUTTING CONDITION

Experiment was performed on centre lathe machine made by Oswal Machinery & Tools Corp Ludhiana Punjab. This is an automatic feed centre lathe with manual depth of cut. Turning operation was performed for machining "Turning is the removal of metal from the outer diameter of a rotating cylindrical workpiece and to produce a smooth finish on the metal"

Fig. 1 show the experimental setup which was used for machining.

Fig: 1. Lathe Machine setup

A. Work piece

In this experiment mild steel in form of circular rod is used as experimental work piece. Circular rod has a length of 110 mm with 55 mm diameter. The chemical composition and physical properties are given in table 1 and table 2 respectively.

Fig: 2. Work piece after machining

TABLE 1
CHEMICAL COMPOSITION OF MILD STEEL WORK PIECE

Element	Composition (%)
Carbon	0.16-0.18%
Silicon	0.40%
Manganese	0.70-0.90%
Sulphur	0.40%
Phosphorus	0.40%
Balance	Fe

TABLE 2
PHYSICAL PROPERTIES OF MILD STEEL WORK PIECE

Physical Properties	Value
Melting point	1427°C
Density	7480-8000 kg/m^3
Tensile strength	440 MPa
Yield strength	370 MPa
Elastic modulus	205 GPa
Hardness (HRB)	71
Electric resistivity	1590 nΩ.m

B. Cutting Tool

Single point carbide tool was used for machining. Photographic view of tool is given below and physical properties of carbide tool are given in table.3

Fig: 3. Tungsten carbide tool

TABLE 3
PHYSICAL PROPERTIES OF CARBIDE TOOL

Mechanical Properties	Value
Molar mass	2.85 g·mol^{-1}
Appearance	Grey-black lustrous solid
Density	15.6 g/cm^3
Melting point	2,785–2,830 °C
Boiling point	6,000 °
Specific heat capacity (*C*)	39.8 J/(mol·K)
Magnetic susceptibility (χ)	1·10^{-5} cm^3/mol
Thermal conductivity	110 W/(m·K)

C. Experimental investigation

There are three control parameters with different level and one response parameters which are depend on control parameters. L9 orthogonal Array is design with the help of Design of Export 9.

TABLE 4
PROCESS PARAMETERS WITH THEIR LEVELS

Response Parameters	**Surface Roughness (µm)**			
Control Parameters	Unit	Levels		
		1	**2**	**3**
Spindle speed	rpm	180	225	425
Feed	mm/rev	0.038	0.075	0.15
Depth of Cut	mm	0.4	0.8	1.2

TABLE 5
L9, ORTHOGONAL ARRAY DESIGN

Spindle speed (rpm)	Feed (mm/rev.)	Depth of Cut (mm)
1	1	1
1	2	2
1	3	3
2	1	3
2	2	1
2	3	2
3	1	2
3	2	3
3	3	1

IV. RESULT AND ANALYSIS OF EXPERIMENT

A. Analysis of S/N Ratio:

General methods of design are so complex and they cannot be easily used because the analysis of these design have a large number of experiments and calculation is so lengthy. To solve this important task, the Taguchi method uses a special design of orthogonal array to study the entire parameter space with only a small number of experiments. The experimental results are then transformed into a signal-to-noise (S/N) ratio. The S/N ratio can be used to measure the deviation of the performance characteristics from the desired values. The categories of performance characteristics in the analysis of the S/N ratio depend upon output parameters to be controlled.

In the Taguchi method, the term 'signal' represents the desirable value (mean) for the output characteristic and the term 'noise' represents the undesirable value (S.D.) for the output characteristics. Therefore, the S/N ratio is the ratio of the mean to the S.D. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value.

The S/N ratio η is defined as

$$\eta = -10 \log (M.S.D.)$$

Where M.S.D = mean-square deviation for the output characteristic.
As mentioned earlier, there are three categories of performance characteristics, i.e., the smaller-the-better, the larger-the better, and the nominal is best. To obtain optimal output performance, the nominal is best must be taken for size variation and the smaller-the-better must be taken for cycle time. The S/N ratio for these quality characteristic can be expressed as: In order to perform S/N ratio analysis, mean square deviation (MSD) for quality characteristics and S/N ratio were calculated from the following equations,
Characteristic smaller the better

$$MSD = \frac{1}{n} \sum y_i^2$$

Where, y_i the surface roughness of i^{th} experiment.

Fig: 4. Surftest SJ-301

TABLE 6
EXPERIMENTAL TABLE FOR SURFACE ROUGHNESS

Exp. No.	Spindle Speed (rpm)	Feed (mm/ rev)	Depth Of Cut (mm)	Surface Roughness (μm)
1	180	0.038	0.4	4.32
2	180	0.075	0.8	4.18
3	180	0.15	1.2	5.24
4	225	0.038	1.2	3.39
5	225	0.075	0.4	3.85
6	225	0.15	0.8	4.25
7	425	0.038	0.8	3.51
8	425	0.075	1.2	3.55
9	425	0.15	0.4	5.37

V. TABLE 7

EXPERIMENTAL TABLE FOR S/N RATIO OF SURFACE ROUGHNESS

Exp. No.	Spindle Speed (rpm)	Feed (mm/ rev)	Depth Of Cut (mm)	SR (μm)	S/N Ratio of SR (db)
1	180	0.038	0.4	4.32	-12.7097
2	180	0.075	0.8	4.18	-12.4235
3	180	0.15	1.2	5.24	-14.3866
4	225	0.038	1.2	3.39	-10.604
5	225	0.075	0.4	3.85	-11.7092
6	225	0.15	0.8	4.25	-12.5678
7	425	0.038	0.8	3.51	-10.9061
8	425	0.075	1.2	3.55	-11.0046
9	425	0.15	0.4	5.37	-14.5995

TABLE 8
RESPONSE TABLE FOR S/N RATIO

Level	Spindle speed (A)	Feed (B)	Depth of Cut (C)
1	-13.17	-11.41	-13.01
2	-11.63	-11.71	-11.97
3	-12.17	-13.85	-12.00
Delta	1.55	2.44	1.04
Rank	2	1	3

From the above table optimal parameters for turning operation were $\mathbf{A_2B_1C_3}$

TABLE 9
RESPONSE TABLE FOR MEANS

Level	Spindle speed (A)	Feed (B)	Depth of Cut (C)
1	4.580	3.740	4.513
2	3.830	3.860	3.980
3	4.143	4.953	4.060
Delta	0.750	1.213	0.533
Rank	2	1	3

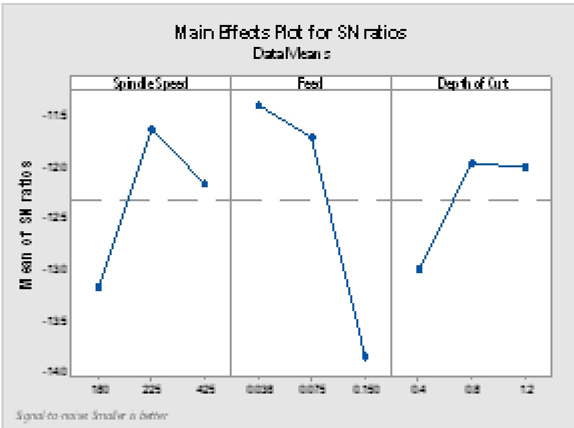

Fig: 5. Main effect plot for S/N ratio

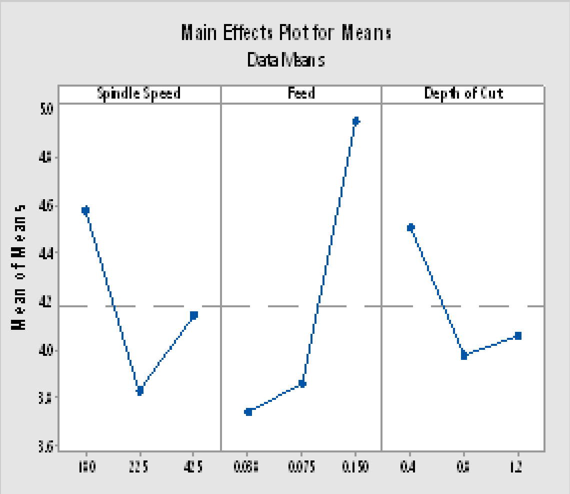

Fig: 6. Main effect plot for means

VI. CONCLUSIONS

In this research mild steel was the work material and cutting tool was carbide. Turning process was used for remove the material from a circular bar. The study discusses about the application of Taguchi method to investigate the effect of process parameters on surface roughness. From the analysis of the results obtained following conclusion can be drawn: -

- Statistically designed experiments based on Taguchi method are performed using L9 orthogonal array to analyze surface roughness. The results obtained from analysis of S/N Ratio were in close agreement.
- Optimal parameters for surface roughness the optimal parameters found were spindle speed 225 rpm; feed 0.075mm/rev and depth of cut 0.8 mm.

ACKNOWLEDGMENT

The Author would like to express their deep gratitude to the management of Bhabha Institute of Technology Kanpur Dehat, for providing the necessary help and moral support. Author is also thankful of research advisor for his support and suggestions during experiential work.

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BIOGRAPHIES

Ravi Patel
(Main Author) P.G student of Bhabha Institute of Technology, Kanpur Dehat (U.P) India. Completed B.tech in Mechanical Engg.

Ankit Kumar,
P.G student of Bhabha Institute of Technology, Kanpur Dehat (U.P) India. Completed B.tech in Mechanical Engg.

Jitendra Kumar Verma
(Research Advisor) Assistant Professor, Mechanical Engg. Deptt. of Bhabha Institute of Technology Kanpur Dehat (U.P) India