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# Optimizing the process parameters of machinability through the Taguchi Technique

Sandeep Malik [1], Mukesh Kumar [2], Yati Parjesh[3]

[1]Assistant Professor, UIET, Maharishi Dayanand University, Rohtak, Haryana, India
[2]Research Scholar, UIET, Maharishi Dayanand University, Rohtak, Haryana, India
[3]Research Scholar, SBMNEC, Maharishi Dayanand University, Rohtak, Haryana, India

**Abstract: CNC machine tool is widely used by manufacturing engineers and production personnel to quickly and effectively set up manufacturing processes for new products .This study discusses an investigation into the use of Taguchi Parameter Design methodology for study of CNC turning operation for surface roughness as a response variable. The Taguchi parameter design method is an efficient experimental method in which a response variable can be study, using fewer experimental runs than a factorial design method. The control parameters for this operation included: spindle speed, feed rate, depth of cut, and tool nose radius. A total of 27 experimental runs were conducted using an orthogonal array, and the ideal combination of controllable factor levels was determined for the surface roughness and signal-to-noise ratio. A confirmation run was used to verify the results, which indicated that this method was both efficient and effective in determining the best turning parameters for the surface roughness.**

**Keywords: Turning operation, Surface Roughness, Machining Parameter, Software Minitab 15, Taguchi Technique, Mild Steel.**

## INTRODUCTION

Metal cutting is one of the most important methods of removing unwanted material in the production of mechanical components. The usual conception of cutting suggests clearing the substance apart with a thin knife or wedge. When metal is cut the action is rather different and although the tool will always be wedge shaped in the cutting area and the cutting edge should always be sharp the wedge angle will be far too great for it to be considered knife shaped. Consequently a shearing action takes place when the work moves against the tool.

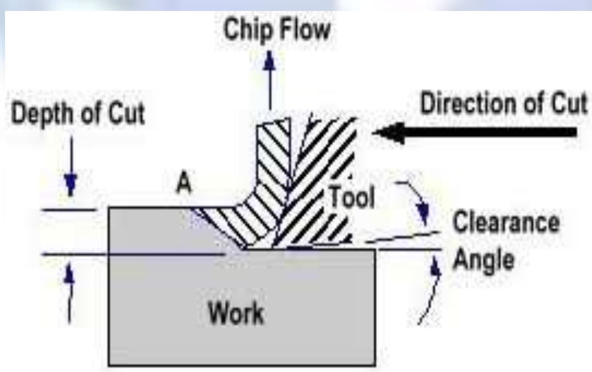


Fig: 1: Basic Metal Cutting Theory

Figure 1 shows a tool being moved against a fixed work piece. When the cut is in progress the chip presses heavily on the top face of the tool and continuous shearing takes place across the shear plane AB. Although this figure shows a tool working in the horizontal plane with the work piece stationary, the same action takes place with the work piece revolving and the tool stationary.

## FUNDAMENTAL MACHINING PARAMETERS

The major operating parameters to be specified in turning are the Cutting speed (V)'. Feed rate ($f_r$), Depth of cut (d) and Tool nose radius(r). For all metal-cutting processes, "speeds and feeds" are important parameters.

**a) Cutting speed (V)**:

The speed is the cutting speed, which is a measure of the part cut surface speed relative to the (here, stationary) tool. It is the largest of the relative velocities of cutting tool or work piece. In drilling and milling, it is the speed of the cutting tool. In Turning, it is given by the surface speed of the work piece. Speed is a velocity unit, which is typically listed in terms of feet/min, inches/min, meters/second, or meters/min.

**b) Feed ($f_r$)**:

It is movement of the tool per revolution. In turning, it is the distance the tool travels in one revolution of the work piece. Feed (Labeled on the figure 2 as $f_r$), is the amount of material removed for each revolution or per pass of the tool over the work piece. Feed is measured in units of length/revolution, length/pass, length/tooth, length/time, or other**.** The term "feed" is used to describe the distance the tool moves per revolution of the work piece and depends largely on the surface finish required. For roughing out a soft material a feed of up to 0.25 mm per revolution may be used. With tougher materials this should be reduced to a maximum of 0.10 mm/rev.

**c) Depth of cut (d):**

The depth of cut (DOC) (Labeled on the figure 2 as d.), represents the third parameter for metal cutting for turning, depth of cut (DOC) is the depth that the tool is plunged into the surface. The DOC is half of the difference in the diameters Da and Db, the initial and final diameters, respectively. It is the distance the cutting tool penetrates into the work piece. For example, it is given by: d = (Da-Db)/2.

$$\text{DOC} = (\text{Depth Of Cut}) = d$$
$$= \frac{D_a - D_b}{2}$$
$$V = \frac{\pi D_a N_s}{12}$$
$$N_s = \text{rpm of workpiece}$$

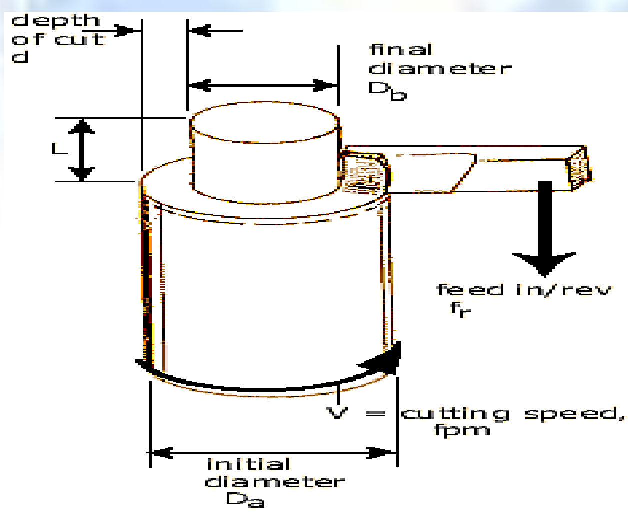


Fig 2: Geometry of fundamental machining parameters

The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Signal to noise ratio and orthogonal array are two major tools used in robu design. For the maximum material removal rate, the solution is "Larger is better" and S/N ratio is determined according to the following equation:

$$S/N = -10\log_{10}\{\frac{1}{n}\sum\frac{1}{y^2}\}$$

where, S/N = Signal to Noise Ratio, n = No. of Measurements, y = Measured Value The influence of each control factor can be more clearly presented with response graphs. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too. Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs.

## LIST OF HARDWARE AND THEIR SPECIFICATIONS

1. CNC lathe
2. Surface roughness measurement device
3. Cutting tool inserts

**1) CNC Lathe:** Envirotech MCL 10 A50 slant bed lathe

IBM-PC based CNC
Spindle speed range: 1,000 rpm minimum, 3500 rpm maximum
Feed rate range: 0.0025 –100 mm per rev
Least input movement increment: X 0.001mm, Z 0.025 mm

Fig 3: Envirotech MCL 10 A50 slant bed lathe IBM-PC based CNC

**2) Surface roughness measurement device:**

Rank Taylor HabsonTalysurf 10 surface texture measuring instrument

Measures Ra in µm
Maximum traversing length: 50.00 mm
Horizontal traversing speed: 3.0 mm/min
Roughness average, Ra: 30-100% of the full scale +_ 2%


Fig 4: Rank Taylor HabsonTalysurf 10

**3) Cutting tool inserts:**

Tools tipped with TiN or TiCN by PVD deposition only is highly advisable for machining Aluminum alloys that contain no more than 7% silicon. Tool used during experimentation are shown in figure 5 Different types of tool used in CNC machining are shown in figure three inserts of different nose radius mention below are used during experimentation. D -55$^0$ Diamonds.

1. (0.2 mm nose radius)
2. (0.3 mm nose radius)
3. (0.4 mm nose radius

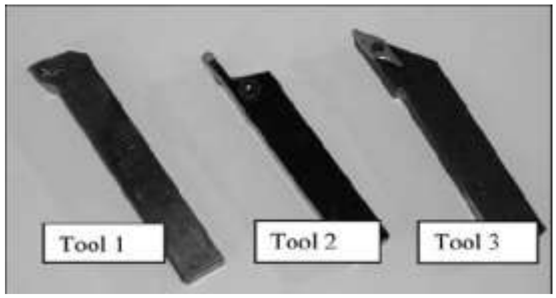


Fig 5: Tool to produce the test piece

(Tool 1 for facing, Tool 2 for parting and Tool 3 for turning)

## WORK MATERIAL

Traditional machining operations such as turning, milling, boring, tapping, sawing etc. are easily performed on M.S. The machines that are used can be the same as for use with steel, however optimum machining conditions such as rotational speeds and feed rates can only be achieved on machines designed for machining M.S.

### Taguchi Orthogonal Array

If there is an experiment having 3 factors which have three values, then total number of experiment is 27. Then results of all experiment will give 100 accurate results. In comparison to above method the Taguchi orthogonal array make list of nine experiments in a particular order which cover all factors. Those nine experiments will give 99.96% accurate result. By using this method number of experiments reduced to 9 instead of 27 with almost same accuracy.

### Process Parameter

**Parameters, codes, and level values used for the orthogonal Array**

Table 1

| **Parameter** | **Code** | **Level 1** | **Level 2** | **Level 3** |
|---|---|---|---|---|
| **Control factors** | | | | |
| Spindle speed (rpm) | A | 1,500 | 2,250 | 3,000 |
| Feed rate (mm/rev) | B | 0.1 | 0.2 | 0.3 |
| Depth of cut (mm) | C | 0.2 | 0.4 | 0.6 |
| Tool radius (mm) | D | 0.2 | 0.3 | 0.4 |

### Design of Experiment

Taguchi's designs aimed to allow greater understanding of variation than did many of the traditional designs. Taguchi contended that conventional sampling is inadequate here as there is no way of obtaining a random sample of future conditions. Taguchi proposed extending each experiment with an "outer array" or orthogonal array should simulate the random environment in which the experiment would function.

**Experimentation**

The whole experimentation is divided into different steps. All the steps are discussed in detail below:

a) Preparation of Job

After doing initial turning on workpiece the diameter is reduced to 10 mm. Workpiece is cut into equal part of length 60mm and measured initial weight of all jobs.

b) Maximum Limits of Operating Parameters

There are three machining parameters i.e. Spindle speed, Feed rate, Depth of cut. Different experiments are done by varying one parameter and keeping other two fixed so maximum value of each parameter was obtained. Operating range is found by experimenting with top spindle speed and taking the lower levels of other parameters. A combination of all three parameters is found beyond which tool or job fails.

**Taguchi Orthogonal Array**

Taguchi orthogonal array is designed with three levels of turning parameters with the help of software Minitab 15. Each three level parameter has 2 degree of freedom (DOF) (Number of level – 1), the total DOF required for three parameters each at three levels is 8[=4x (3-1)]. As per Taguchi's method the total DOF of the OA must be greater than or equal to the total DOF required for the experimentation. So an $L_9$ OA (a standard 3- level OA) having 8(=9-1) degree of freedom was selected for the present analysis. The standardized Taguchi-based experimental design used in this study was an $L_9$ ($3_4$) orthogonal array, as described shown in below table 2.

Table 2: The basic Taguchi $L_9$ ($3_4$) orthogonal array

| **Run** | **Control factors and levels** | | | |
|---|---|---|---|---|
| | **A** | **B** | **C** | **D** |
| 1 | 1 | 1 | 1 | 1 |
| 2 | 1 | 2 | 2 | 2 |
| 3 | 1 | 3 | 3 | 3 |
| 4 | 2 | 1 | 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 |

This basic design uses up to four control factors, each with three levels. A total of nine runs must be carried out, using the combination of levels for each control factor (A through D).The addition of noise factors is optional, and requires each run to be conducted once for each combination of noise factor. The selected parameters, discussed in the introduction, are listed in table 1, along with their applicable codes and values for use in the Taguchi model. The control and noise factors are independent variables, and the response variable is the dependent variable. The control factors are the basic, controlled parameters used in a turning operation. The noise factors are often uncontrolled variables in machine shops which may affect the surface roughness of a turning operation. The selected factors were considered because that could be controlled in an experimental setup.

A modified orthogonal array, table 3 was created using the basic Taguchi orthogonal array and the selected parameters from table 1. In this array, the basic array with the control factors are shown as the inner control factor array and the added repetitions the outer noise array.

Table 3: Modified Taguchi $L_9$ $(3^4)$ orthogonal array

| Inner Control Factor Array | | | | Outer Control Factor Array | | |
|---|---|---|---|---|---|---|
| SpindleSpeed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool Radius (mm) | Y1 | Y2 | Y3 |
| 1500 | 0.1 | 0.2 | 0.2 | 1.35 | 1.85 | 1.52 |
| 1500 | 0.2 | 0.4 | 0.3 | 3.36 | 3.12 | 3.46 |
| 1500 | 0.3 | 0.6 | 0.4 | 4.07 | 3.47 | 3.13 |
| 2250 | 0.1 | 0.4 | 0.4 | 1.2 | 1.13 | 0.83 |
| 2250 | 0.2 | 0.6 | 0.2 | 3.97 | 4.47 | 4.6 |
| 2250 | 0.3 | 0.2 | 0.3 | 5.47 | 5.92 | 5.34 |
| 3000 | 0.1 | 0.6 | 0.3 | 1.16 | 1.04 | 1.17 |
| 3000 | 0.2 | 0.2 | 0.4 | 1.21 | 2.65 | 1.4 |
| 3000 | 0.3 | 0.4 | 0.2 | 6.16 | 5.97 | 5.94 |

Also indicated here is the required repetition for each run for each combination of noise factors and different measurement are Y1, Y2, Y3, .All of the experimental are repeated three times.

## EXPERIMENTATION AND DATA COLLECTION

The next step is to design the matrix experiment and define the data analysis procedure. The experiment is performed against each of the trial conditions of the inner array. Each experiment at a trial condition is repeated simply three times (if outer array is not used) or according to the outer array (if used). Randomizations were carried for to reduce bias in the experiment. The spindle speed, feed rate, and depth of cut parameters were programmed into the CNC program. The tool inserts were changed as needed to obtain the prescribed radius, and to alternate between the in each set. The surface roughness measurement process included the use of a Talysurf 10, as well as all the necessary hardware to align the stylus motion perpendicular to the axis of the turned part during the measurement. The maximum surface roughness measurement (maximum $R_a$) of each cut was recorded for analysis.

The results of the surface roughness measurements $R_a$ (µm) of each sample are shown in table 3, along with the additional parameters of the expanded orthogonal array. The individual surface roughness measurements are noted in the array. A final column has been added to this array, to indicate the signal-to-noise (S/ N) ratio, calculated as follows:

$$\eta = -10\log\left[\frac{1}{n}\left(\sum y_i^2\right)\right]$$

Where η is the S/N ratio,

- $y_i$ are the individual surface roughness measurements in columns Y1 through Y3, and
- nis the number of repetitions; in this case, n=3.

## DATA ANALYSIS

The experiment was planned by using the parametric approach of the Taguchi method. A number of methods have been suggested by Taguchi for analyzing the data observation method, ranking method, column effect method, ANOVA, S/N ANOVA, plot of average responses, interaction graphs, etc.

## RESULTS & DISCUSSION

After finding all the observation, S/N ratio and Means are calculated and various graph for analysis is drawn by using Minitab 15 software. The S/N ratio for MRR is calculated on Minitab 15 Software using Taguchi Method. The steps used are as follows:

**Starting Minitab 15**: To start Minitab, click shortcut of Minitab on Desktop of computer. A window is opened in computer as shown in Figure:

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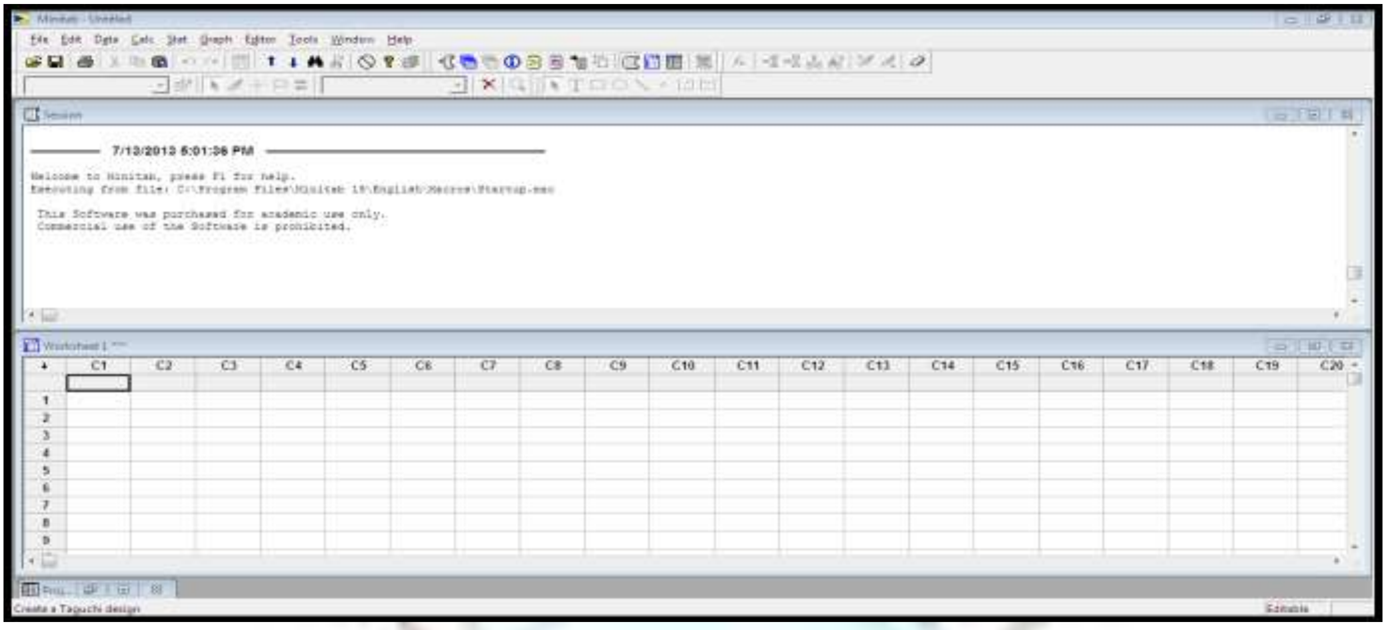
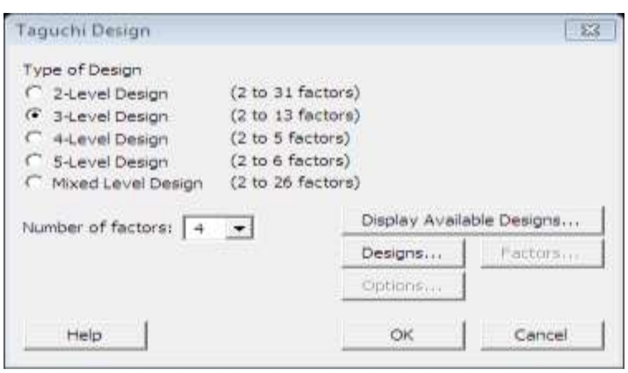


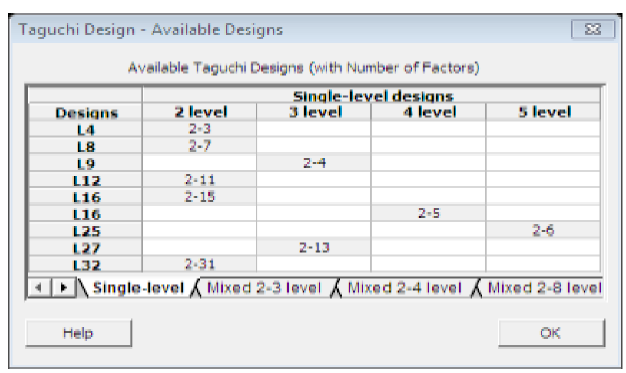

**Minitab Software**

**Minitab Software Design of Orthogonal Array**

First Taguchi Orthogonal Array is designed in Minitab15 to calculate S/N ratio and Means which steps is given below:


**Create Taguchi Design**




**Taguchi Design** **Taguchi Design Available**

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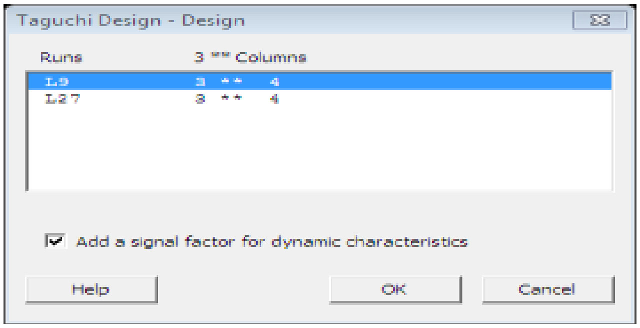
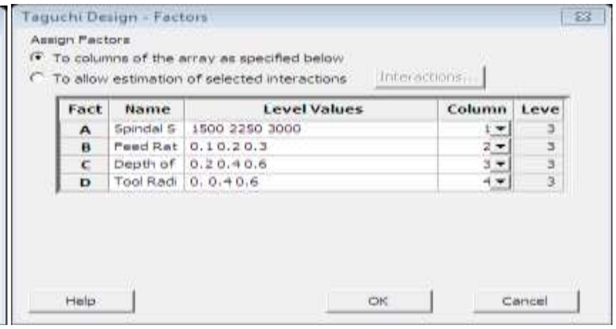
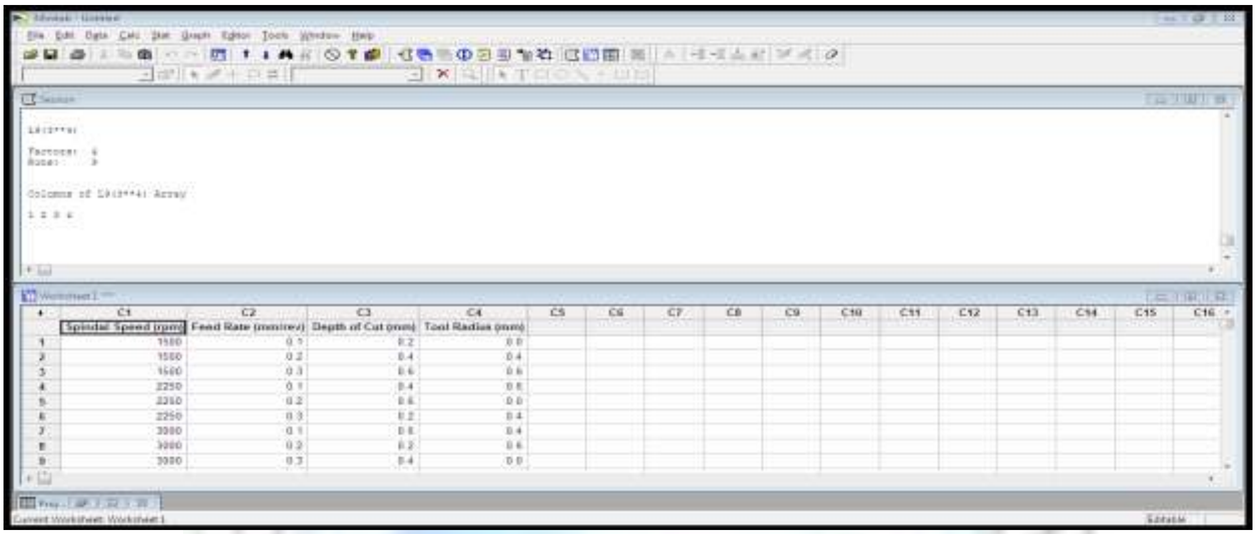
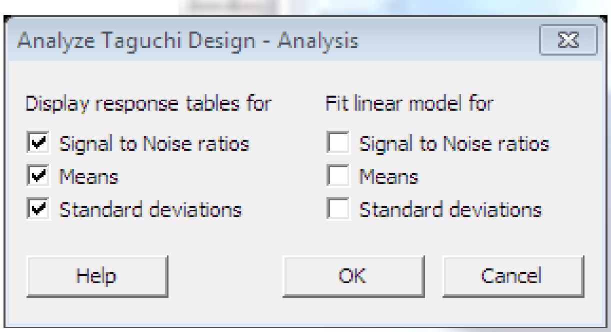
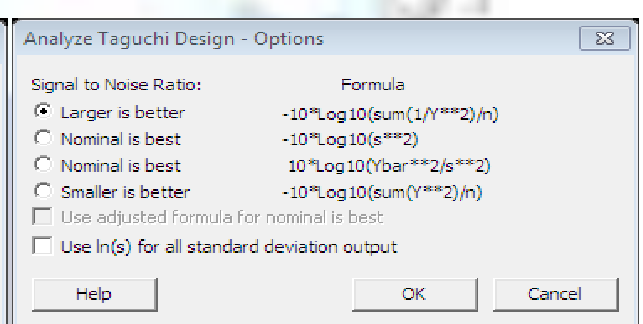


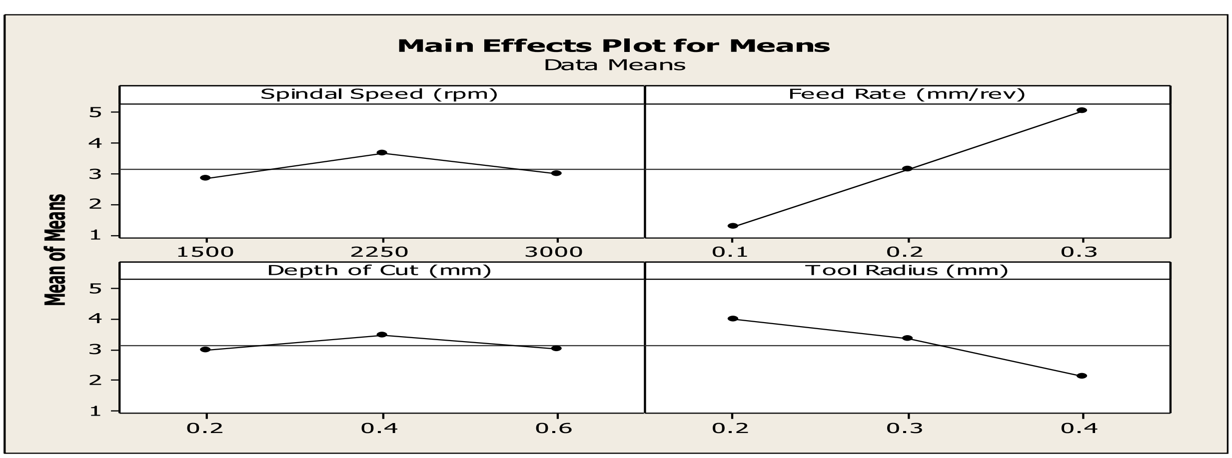



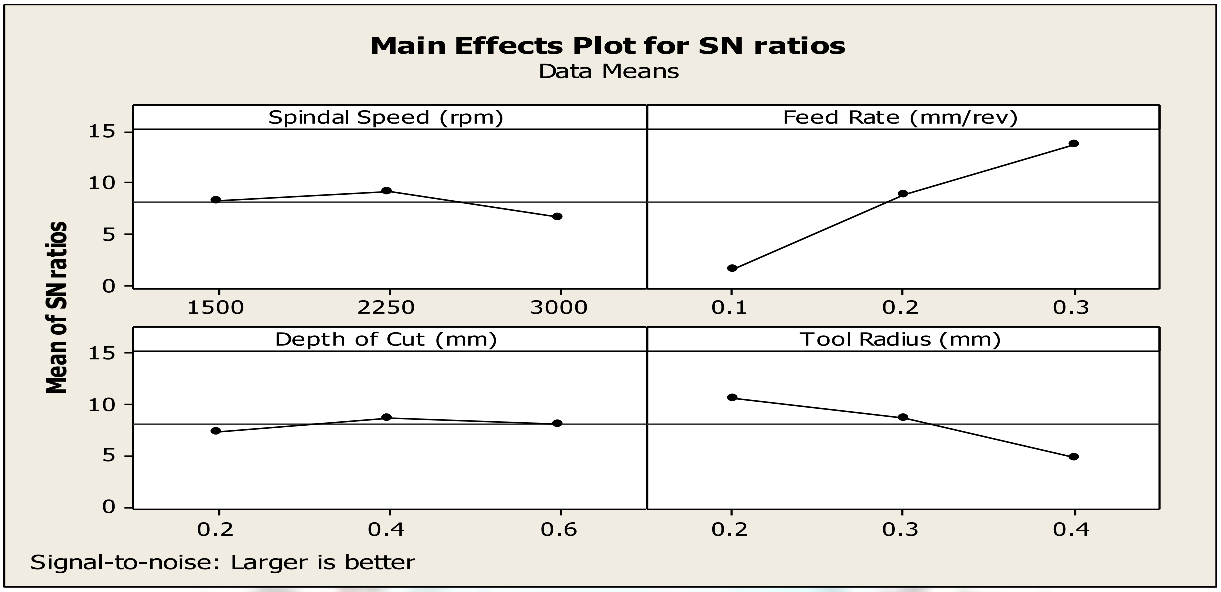



**Main Effects Plot for Means**



**Main Effects Plot for SN ratios**




**Response Table for Signal to Noise Ratios**
**Larger is better**

| Level | Spindle Speed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool Radius (mm) |
|---|---|---|---|---|
| 1 | 8.324 | 1.599 | 7.379 | 10.674 |
| 2 | 9.239 | 8.868 | 8.693 | 8.752 |
| 3 | 6.693 | 13.789 | 8.184 | 4.830 |
| Delta | 2.545 | 12.190 | 1.313 | 5.845 |
| Rank | 3 | 1 | 4 | 2 |

**Response Table for Means**

| Level | Spindle Speed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool Radius (mm) |
|---|---|---|---|---|
| 1 | 2.814 | 1.250 | 2.968 | 3.981 |
| 2 | 3.659 | 3.138 | 3.463 | 3.338 |
| 3 | 2.967 | 5.052 | 3.009 | 2.121 |
| Delta | 0.844 | 3.802 | 0.496 | 1.860 |
| Rank | 3 | 1 | 4 | 2 |

**Response Table for Standard Deviations**

| Level | Spindle Speed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool Radius (mm) |
|---|---|---|---|---|
| 1 | 0.3016 | 0.1744 | 0.4470 | 0.2354 |
| 2 | 0.2778 | 0.4299 | 0.1635 | 0.1838 |
| 3 | 0.3247 | 0.2999 | 0.2936 | 0.4849 |
| Delta | 0.0468 | 0.2555 | 0.2834 | 0.3011 |
| Rank | 4 | 3 | 2 | 1 |

**Taguchi Analysis: Y1, Y2, ... versus Spindle Speed, Feed Rate (m, ...**

**Predicted values**

| S/N Ratio | Mean | StDev |
|---|---|---|
| 3.72052 | 1.57333 | 0.254231 |

**Factor levels for predictions**

| Spindle Speed (rpm) | Feed Rate (mm/rev) | Depth of Cut (mm) | Tool Radius (mm) |
|---|---|---|---|
| 1500 | 0.1 | 0.2 | 0.2 |

## CONCLUSION

This study presented an efficient method for determining the optimal turning operation parameters for surface finish under varying conditions through the use of the Taguchi parameter design process. This process was applied using a specific set of control and noise parameters, and a response variable of surface roughness. The use of the $L_9$ ($3^4$) orthogonal array, with four control parameters allowed this study to be conducted with a sample of 27 work pieces. The study found that the control factors had varying effects on the response variable, with feed rate and tool nose radius having the highest effects. The noise factors, on the other hand, were found to not have a statistically noticeable effect. The study led to the selection of a combination of levels for each control parameter, which were used to create an additional sample of 10 work pieces. The measurement of the work pieces in this confirmation run led to the conclusion that the selected parameter values from this process produced a surface roughness that was much lower than the other combinations tested in this study. Taguchi method has been very successful in designing high-quality products and processes of many different fields. In it the design horizon is enlarged to all technical and economical properties important to the product. The strategic analysis on the effect of noises in the early design phase is superior to conventional procedures. The numerous combinations of design parameter settings cannot efficiently be controlled by human judgment, which results in time and cost consuming but can easily be controlled by using DOE techniques. The Taguchi methods offers a strategy for finding optimal, stable results based on a predefined set of analyzed parameter combinations. Robust Design takes up the concepts of the Taguchi method and offers a standard, homogenous procedure based on actual and scientific knowledge. Design of experiment is expected to gain more accurate answers on system behavior and interaction effects, especially when created on basis of fractional factorial designs.

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