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# Effect of overhanging of tool, cutting speed and feed rate on surface roughness of SW17 hexagon produced on CNC turning machine with C-axis

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**Abstract:** The research aims to investigate the effects of overhanging of tool, cutting speed and feed rate on surface roughness of EN8 material while producing hexagon of SW17 on CNC Turning machine with C-axis. The cutting tool used in this research is HSS parallel shank 4 flute end mill. Taguchi based design of experiments are applied to develop an $L_9$ orthogonal array for experimental runs. Results are recorded and analysed by using Taguchi S/N ratios with the consideration of performance characteristic of smaller the better as surface roughness values are required to be low. From the study of response table for S/N ratios, it can be concluded that cutting speed had a major effect on surface roughness followed by overhanging of tool and feed rate. The optimum values obtained are Overhanging of tool of 39.6 mm (55%), Cutting speed of 20 m/min, Feed rate of 65 mm/min. ANOVA methodology is used in this research to check the dependency of the surface roughness upon the corresponding input parameters. The results obtained clearly signified that feed rate is most significant followed by overhanging of tool and cutting speed and thus affects the average surface roughness.

## 1. Introduction

CNC is the abbreviation of Computer Numerical Control. This means a computer is used to convert the designs into alpha-numeric data (known as Programs) which controls the work piece rotation as well as cutter movement [8]. CNC Turning process is defined as a machining process used to produce cylindrical parts by rotating the work piece and by moving the tool parallel to the axis of rotation of the work piece with the use of Computer Numerical Control.

### 1.1 CNC Turning with C-Axis

CNC turning is generally having two axis, X-Axis and Z-Axis. X-Axis is the axis of motion which is always perpendicular to the axis of spindle while Z-Axis is always parallel to the axis of spindle. CNC turning with C-Axis have the ability to perform the turning and milling operation on the same machine tool as its spindle can be treated as another axis, known as C-Axis. C-axis allows the work piece to be positioned at any angle. These also have the feature of live tooling which means end mills, slot drills, taps, etc. can be clamped and rotated in turret, keeping the work piece stationary. End mills and Slot drills are cutting tools used to create contours, slots, profiles, etc. however slot drills can also plunge into the work piece [9].

### 1.2 Surface Roughness

Surface Roughness is one of the key index in terms of the quality of the product. It is defined as the measurement of the irregularities on the surface texture of the work piece. Denoted by $R_a$ which represents average values of irregularities i.e. average surface roughness. These irregularities should be minimum as required by Industries for better surface finish [1-2].

Surface finish is affected by machining parameters (cutting speed, feed rate, depth of cut, cutting fluid), mechanical properties of the work piece material, tool properties and cutting process characteristics.Cutting speed (V) is defined as the speed at which the cutting tool is removing the material from the work piece. It is expressed in m/min [10]. In turning, one millimetre relative motion of tool in one revolution of work piece represents the feed of 1 mm/rev [10]. In milling, it is expressed in mm/min.

### 1.3 Polygons

Polygon is defined as a closed figure having 3 or more straight sides like triangle, pentagon, hexagon, octagon, etc. [11]. Hexagon is the widely used shape in screws. In this study, a hexagon is made on CNC turning machine using C-axis for SW17 Wrench as shown in figure 1.

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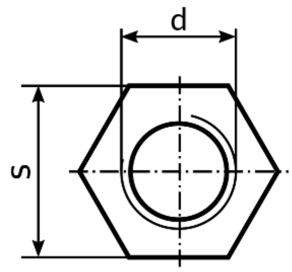



d- nominal thread diameter
s-wrench size

**Fig. 1**: Hexagon of a Screw with wrench size “s” and nominal thread diameter “d” [12].

### 1.4 Objectives

1. Effect of Overhanging of tool, Cutting speed and Feed rate on Surface Roughness of SW17 hexagon produced on CNC Turning Machine with C-Axis.
2. To develop an orthogonal array for experimental runs and statistically signify the relationships between input parameters (cutting speed, feed rate, overhanging of tool) and output responses (surface roughness) using Taguchi based Design of Experiments technique on Minitab statistical software.
3. To predict the response using S/N ratios and to analyse and validate the outputs obtained using ANOVA technique.

## 2. Literature Review

Several studies have been carried out to optimize the effects of machining parameters on surface roughness on different materials.

Ghazali et al., [2] investigated the surface roughness for aluminium, mild steel and brass materials turned on CNC Lathe machine. The effective parameters chosen were feed rate and cutting speed. The author concluded from the experiment that surface roughness of different materials increases as the feed rate increases and decreases as the cutting speed increases. Surface roughness ($R_a$) values obtained from the experiment were also compared with the theoretical values with discrepancy ranging from 1.14% to 113.71% in the study. Samya et al., [7] used Taguchi orthogonal array $L_9$ for various combinations of four turning parameters (cutting speed, feed rate, depth of cut and nose radius) in the study. Taguchi design is used to identify the optimal combination of parameters to minimize the surface roughness. The author used the confirmation test and regression model to confirm the effectiveness of the Taguchi optimization.

Ranganath et al., [5] conducted experiments on mild steel material and used carbide (CNMG-120408-TTR) as a cutting tool to perform the turning operation. The effect of cutting parameters on surface roughness was analysed by Analysis of Variance (ANOVA) which concluded that depth of cut is the most dominant parameter followed by feed rate and cutting speed when good surface finish is required. Minimum surface roughness obtained at 1350 rpm, 0.15 mm/rev and 0.2 mm parameters in the research. One more study by the author suggested that the cutting speed is the most influential process parameters on surface roughness of Aluminium 6061, keeping the feed rate and depth of cut as low as possible. The maximum surface finish obtained at speed of 1900 rpm, feed rate of 0.12 mm/rev and depth of cut 0.25 mm [6].

Rao et al., [3] concluded the depth of cut as the most dominant factor followed by feed rate and spindle speed in the study for surface roughness of a particular type of MWCNT Epoxy composite material during end milling process using CNC Milling machine. Taguchi and ANOVA are used for optimization and analysing the process parameters and achieved optimal surface roughness value at highest feed rate of 30 mm/min, lowest cutting speed of 1000 rpm and lowest depth of cut of 0.4 mm. Ghan et al. [4] investigated the effects of various parameters like cutting tool material, geometry, cutting parameters and machine tools. Research was conducted on Aluminium LM-26 Alloy to study the effects of turning and milling parameters on manufacturing processes.

From the literature available in this field, it has been observed that many researchers worked on different materials with different tools to achieve the optimal machining parameters (cutting speed, feed rate and depth of cut) for minimum surface roughness. The scope observed in this field is that researchers did not consider the effects of tool overhang together with cutting speed and C-Axis feed rate while peripheral milling of hexagon for SW17 wrench on CNC Turning with C-Axis.

## 3. Methodology

### 3.1 Taguchi Methods

Taguchi methods was developed by a Japanese Engineer, Genichi Taguchi to improve the quality of goods and to optimize designs for cost, quality and performance. In this research, Taguchi based design of experiments are applied to develop an $L_9$ orthogonal array for experimental runs and statistically signify the relationships between input parameters (cutting speed, feed rate, overhanging of tool) and output responses (surface roughness). In this study, three parameters with three levels forms a Taguchi $L_9$ orthogonal array.

### 3.2 Signal-to-Noise Ratio

SNR or S/N ratio is a useful parameter that compares the level of desired signal to the level of background noise. It is also used to analyse the data obtained and could predict the results. A large S/N ratio is always desirable as it represents good quality. S/N ratio is separated into three groups or three performance characteristics: -

- Smaller the better
  $S/N = -10 * \log(\Sigma(Y^2)/n))$ (1)
- Nominal the best
  $S/N = -10 * \log(\sigma^2)$ (2)
- Larger the better
  $S/N = -10 * \log(\Sigma(1/Y^2)/n)$ (3)

In this study, smaller the better consideration is taken into account because the surface roughness values should be as low as possible for better quality.

### 3.3 Analysis of Variance (ANOVA)

ANOVA is developed by Ronald Fisher. It uses the statistical models to analyse and compare more than two groups at the same time to determine the relationship between them. In this study, a two-way ANOVA is used to tests the effects of two factors (cutting speed & feed rate) at the same time on the output parameter (surface roughness).

## 4.Experimental Work

### 4.1 Workpiece Material

The material used in this research is EN8 (unalloyed medium carbon steel) in the form of round bars with *20 mm* diameter and *30* mm of total length. The workpiece is turned upto diameter (D) 19.62 mm and 15 mm length to make a hexagon of side length (S) 9.81 mm for SW17 wrench size shown in figure 2. Mechanical properties of EN8 are shown is Table 1. Also Chemical composition is shown in Table 2.

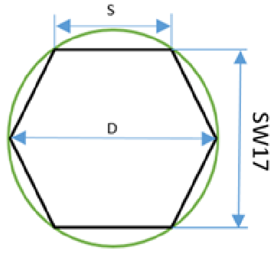



**Fig. 2**: Hexagon of side length S, diameter D, and wrench size SW17.

**Table 1**: Mechanical Properties of EN8 in R condition.

| **Properties** | **Values** |
|---|---|
| Maximum Stress | 700-850 N/mm$^2$ |
| Yield Stress | 465 N/mm$^2$ |
| Elongation | 16 % Min. |
| Hardness | 201-255 Brinell |

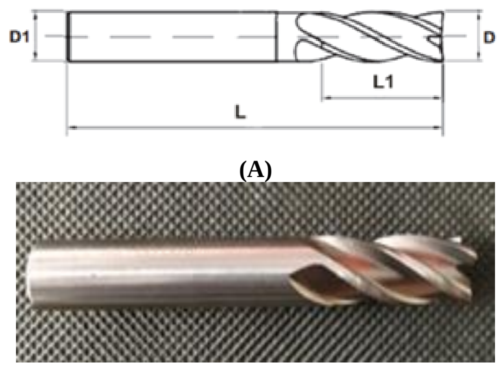
**Table 2:** Chemical Composition of EN8.

| Element | Content |
|---|---|
| Carbon (C) | 0.36 – 0.44 % |
| Silicon (Si) | 0.10 – 0.40 % |
| Manganese (Mn) | 0.60 – 1.00 % |
| Sulphur (S) | 0.050 Max. |
| Phosphorus (P) | 0.050 Max. |

**Fig. 3**: Workpieces used for experiment trials.

### 4.2 Cutting Tool

The cutting tool used in this research is HSS parallel shank 4 flute Endmill with cutting diameter D of 10 mm, shank diameter D1 of 10 mm, flute length of L1 of 22 mm and overall length L of 72 mm shown in figure 4 [13]. Tool is clamped in the spring collet type holder and rotates parallel to the longitudinal axis of the workpiece.




**(B)**

**Fig. 4**: (A) Parallel shank 4F Endmill with designated dimensions [15], (B) Cutting tool used for experimental runs.

### 4.3 Machine

The machine used in this research is CNC Turning (Emco Concept Turn 250) with X, Z and C axis manufactured by Emco, Austria. The experiments are performed on this machine in Bhartiya Skill Development University, Jaipur. Technical specifications of the machine are given in table 3 and the machine used for experiment trials is shown is figure 5.

**Table 3:** Technical specification of Emco Concept Turn 250.

| Specifications | Values |
|---|---|
| **Working Area** | |
| Swing over bed | Ø 250 mm |
| Maximum turning diameter | Ø 85 mm |
| Maximum part length | 225 mm |
| **Drive Main Spindle** | |
| AC motor, capacity (100%/40%ED) with integrated brake for driven tools | 3.7 / 5.5 kW |
| Speed range (infinitely variable) | 50 – 6300 rpm |
| Maximum torque | 35 Nm |
| **C-Axis** | |
| Resolution of the round axis | 0.01° |
| Rapid traverse | 1000 rpm |
| **Driven Tool Stations** | |
| Torque (20% d.c.) | 4 Nm |
| Speed range | 50 – 6000 rpm |
| Max. output (20% ED) | 1.2 kW |
| **Coolant Device** | |
| Tank capacity | 140 litres |
| Pump power | 0.57 kW |

## 4.4 Coolant

Coolant used in this research is Strub Stabillocut IB50 by Strub India Pvt. Ltd. with a pump power of *0.57kW*. The concentration of the coolant used in the experiments is *6%* as measured by an instrument called Refractometer and pH of the coolant is *8.*


**Fig. 5**: CNC Turning with C-Axis (Emco Concept Turn 250)

## 4.5 Surface Roughness Tester

Surface Roughness Tester is a measuring instrument used to measure the roughness (Ra & Rz) values. The surface roughness tester used in this research is portable Surftest SJ-410 from Mitutoyo as shown in figure 6.

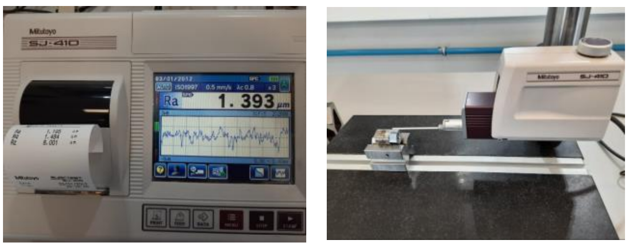



**Fig. 6:** Surface Roughness Tester

## 4.6 Parameters and Levels of Experiments

In this research, three parameters i.e. overhanging of tool, cutting speed and feed rate are taken into consideration. Three levels are selected for each parameter as shown in table 4. Feed rate of C-Axis is taken in mm/min (with feed per tooth of 0.03, 0.05 and 0.08 mm/rev respectively) as milling operation is performed while producing hexagon.

**Table 4:** Parameters and Levels of Experiments

| Parameters | Unit | Levels | | |
|---|---|---|---|---|
| | | **Level 1** | **Level 2** | **Level 3** |
| **Overhanging of tool (O)** | mm | 54 (75%) | 46.8 (65%) | 39.6 (55%) |
| **Cutting Speed (V)** | m/min | 20 | 25 | 30 |
| **Feed rate (C-Axis), (f)** | mm/min | 25 | 65 | 115 |

## 4.7 Experimental Data

In this research, Taguchi based design of experiments are applied to develop an $L_9$ orthogonal array for experimental runs by using Minitab software 19 given in table 5. Total 9 experiments have been performed with three input parameters (overhanging of tool, cutting speed and feed rate) and one output response (surface roughness "Ra") given in table 6. The measurement of surface roughness value is repeated twice (Ra1 and Ra2) at two opposite sides of hexagon and average of Ra1 and Ra2 is taken as Ra.

**Table 5:** Experimental Data

| **Exp. Order** | **Overhanging of Tool (O)** | **Cutting Speed (V)** | **Feed Rate (f)** |
|---|---|---|---|
| | **(mm)** | **(m/min)** | **(mm/min)** |
| 1 | 54.0 | 20 | 25 |
| 2 | 54.0 | 25 | 65 |
| 3 | 54.0 | 30 | 115 |
| 4 | 46.8 | 20 | 65 |
| 5 | 46.8 | 25 | 115 |
| 6 | 46.8 | 30 | 25 |
| 7 | 39.6 | 20 | 115 |
| 8 | 39.6 | 25 | 25 |
| 9 | 39.6 | 30 | 65 |

## 5.Result Analysis

On the basis of result obtained given in table 6, S/N ratio is determined using Minitab 19 for corresponding surface roughness values. It is evident from the table 6 that large S/N ratio is corresponding to minimum Ra value with consideration the performance characteristics of smaller the better. It is clear from the table 7 that cutting speed is having major effect on surface roughness followed by overhanging of tool and feed rate as observed by the following delta values and ranks in the table 7.

**Table 6:** Experimental results with output response and S/N ratio.

| Exp. Order | Overhanging of Tool "O" | Cutting Speed "V" | Feed Rate "f" | Surface Roughness "Ra1" | Surface Roughness "Ra2" | Avg. Surface Roughness "Ra" | S/N Ratio |
|---|---|---|---|---|---|---|---|
| | (mm) | (m/min) | (mm/min) | (μm) | (μm) | (μm) | (dB) |
| 1 | 54.0 | 20 | 25 | 1.195 | 1.393 | 1.294 | -2.23869 |
| 2 | 54.0 | 25 | 65 | 1.217 | 1.061 | 1.139 | -1.13047 |
| 3 | 54.0 | 30 | 115 | 1.583 | 1.715 | 1.649 | -4.34441 |
| 4 | 46.8 | 20 | 65 | 1.067 | 1.187 | 1.127 | -1.03848 |
| 5 | 46.8 | 25 | 115 | 1.360 | 1.582 | 1.471 | -3.35225 |
| 6 | 46.8 | 30 | 25 | 1.371 | 1.773 | 1.572 | -3.92905 |
| 7 | 39.6 | 20 | 115 | 1.208 | 0.952 | 1.080 | -0.66848 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | 39.6 | 25 | 25 | 1.183 | 1.146 | 1.165 | -1.32652 |
| 9 | 39.6 | 30 | 65 | 1.279 | 1.472 | 1.376 | -2.77237 |

**Table 7:** Response table for Signal to Noise ratios.

| Level | O | V | f |
|---|---|---|---|
| **1** | **-1.589** | **-1.315** | -2.498 |
| **2** | -2.773 | -1.936 | **-1.647** |
| **3** | -2.571 | -3.682 | -2.788 |
| **Delta** | 1.184 | 2.367 | 1.141 |
| **Rank** | **2** | **1** | **3** |

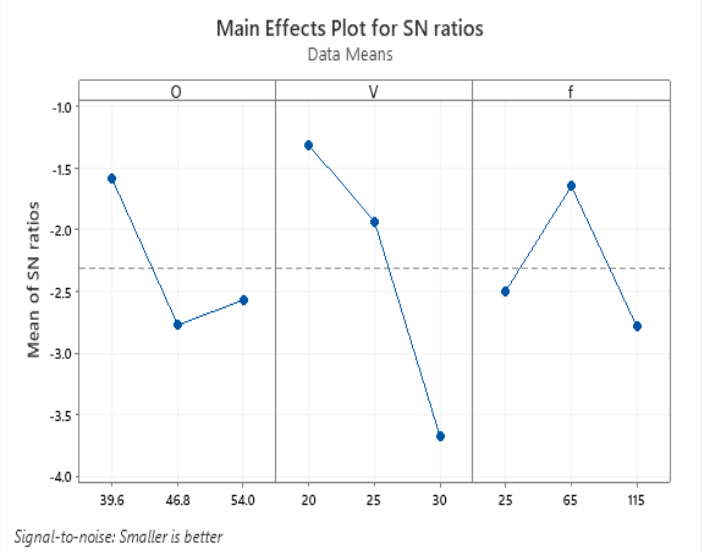



**Fig. 7:** Effects of overhanging of tool, cutting speed and feed rate on S/N ratio.

It is clear from the figure 7 that S/N ratio is decreasing with increasing overhanging of tool and with increasing cutting speed. Also it is evident that large S/N ratio is corresponding to the medium feed rate value. So, on the basis of the results obtained from table 7 and figure 7, optimum input parameters for minimum surface values are given below.

- Overhanging of tool of 39.6 mm (55%).
- Cutting speed of 20 m/min.
- Feed rate of 65 mm/min.

ANOVA methodology is used in this research to analyse the data obtained. For this, hypothesis is assumed to check the dependency of the surface roughness upon the corresponding input parameters and hypothesis is defined as follows:

- Null hypothesis ($H_0$): Surface roughness will be affected by change in the input values.
- Alternate hypothesis ($H_1$): Surface roughness will not be affected by change in the input values.

F values will explain the significant effect of one of the three input parameters on surface roughness. A high value of F will reject the null hypothesis. We also get the P values in this test and a higher P value indicates more effect of that input variable on surface roughness. Three input factors each with three levels are chosen in this study and results obtained are analysed using Minitab 19 software. Factor information is given in table 8.

**Table 8:** Factor Information.

| Factors | Type | Levels | Values |
|---|---|---|---|
| **O** | Fixed | 3 | 39.6, 46.8, 54.0 |
| **V** | Fixed | 3 | 20. 25, 30 |
| **f** | Fixed | 3 | 25, 65, 115 |

**Table 9:** Result of ANOVA analysis for Ra.

| Source | DF | Adj. SS | Adj. MS | F-Value | P-Value | $F_{0.05}$ Table Value | $F_{0.10}$ Table Value |
|---|---|---|---|---|---|---|---|
| O | 2 | 0.05796 | 0.02898 | 2.82 | 0.262 | 19.000 | 9.0000 |
| V | 2 | 0.21689 | 0.10844 | 10.55 | 0.087 | 19.000 | 9.000 |
| f | 2 | 0.05458 | 0.02729 | 2.66 | 0.274 | 19.000 | 9.000 |
| Error | 2 | 0.02056 | 0.01028 | | | | |
| Total | 8 | 0.34999 | | | | | |

## 5.1 Estimated model coefficients for Ra

S = 0.101379 R-Sq = 94.13% R-Sq (adj) = 76.51%

It is evident from the table 9 that null hypothesis ($H_0$) is accepted for all three input variables at 95% confidence level as F-value is less than the $F_{0.05}$ table value whereas null hypothesis is accepted for two input variables and rejected for one input variable (cutting speed) at 90% confidence level as F-value is greater than $F_{0.10}$ table value.

It is also evident from the table 9 that P-value is more for feed rate than overhanging of tool and minimum for cutting speed so feed rate is most significant followed by overhanging of tool and cutting speed and thus affects the average surface roughness.

## 5.2 Regression equation obtained from ANOVA analysis

Ra = 1.3192 - 0.1122 O_39.6 + 0.0708 O_46.8 + 0.0414 O_54.0 - 0.1522 V_20- 0.0609 V_25+ 0.2131 V_30 + 0.0244 f_25 - 0.1052 f_65 + 0.0808 f_115

# 6. Conclusions

In this research, Taguchi based design of experiments are applied to develop an $L_9$ orthogonal array for experimental runs. Three input parameters i.e. overhanging of tool, cutting speed and feed rate are selected each with three levels to signify their effects on surface roughness. Nine experiments are conducted and results are recorded and analysed by using Taguchi S/N ratios with the consideration of performance characteristic of smaller the better as surface roughness values are required to be low. The results obtained from the response table for S/N ratios determined that cutting speed had a major effect on surface roughness followed by overhanging of tool and feed rate as observed by the delta values and ranks. The optimum input parameters obtained from the main effect plot for S/N ratios for minimum surface roughness values are given below:

- Overhanging of tool of 39.6 mm (55%).
- Cutting speed of 20 m/min.
- Feed rate of 65 mm/min.

Anova methodology is used in this research to check the dependency of the surface roughness upon the corresponding input parameters. The results obtained clearly signified that P-value is more for feed rate than overhanging of tool and minimum for cutting speed so feed rate is most significant followed by overhanging of tool and cutting speed and thus affects the average surface roughness. So from the results obtained by using different methodologies in this research, it is concluded that surface roughness values are always affected by overhanging of tool to an extent together with machining parameters when cutting tool rotates parallel to the longitudinal axis of the workpiece. It is also concluded that surface roughness decreases with the increase in cutting speed.

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