# Precision Parameter Optimization for Superior Surface Finish in Medium Carbon Alloy Turning

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The quality and productivity in manufacturing technology are paramount for ensuring customer satisfaction and operational efficiency. Surface roughness, a key indicator of product quality, directly affects the degree of satisfaction in manufacturing outcomes. This study explores the optimization of process parameters in turning medium carbon alloy material using a lathe and coated carbide inserts. The research employed Taguchi's design of experiment (DOE) methodology and regression analysis to enhance the surface finish under dry cutting conditions. Four distinct types of coated carbide inserts with nose radii of 0.4 mm, 0.8 mm,1.2 and 1.4 mm were tested. The experiments were structured based on an L16 standard orthogonal array design to systematically vary and analyse the impact of four process parameters: cutting speed, feed rate, depth of cut, and nose radius. The "smaller-the-better" approach was chosen as the objective criterion for surface roughness minimization.

**Keywords:** Machining, Surface Roughness, Orthogonal Array, ANOVA, carbide inserts.

## 1. Introduction

The turning process is an essential and widely used manufacturing technique involving the removal of material from a rotating work piece using a stationary single-point cutting tool. This method is primarily employed to achieve a high-quality surface finish, which is critical from both production and customer satisfaction perspectives. The quality of a turned surface has significant implications for product performance, particularly when considering aspects such as fatigue strength, corrosion resistance, and creep life. These properties are essential for extending the service life of components, ensuring reliability, and maintaining performance under operational stresses [1].

Surface roughness is influenced by various factors during machining operations, including process parameters such as cutting speed, feed rate, depth of cut, and tool characteristics like material, nose radius, rake angle, and cutting edge geometry. Additionally, tool vibration, overhang, and point angle play significant roles. The work piece itself, particularly its hardness and mechanical properties, also impacts the outcome. Achieving a high-quality surface finish necessitates precise selection of these machining parameters.

The Taguchi method is an effective statistical approach used to optimize process parameters in order to achieve desired performance characteristics. This method employs tools such as signal-to-noise (S/N) ratios and orthogonal arrays to design robust experiments. The S/N ratio measures quality with a focus on reducing variation, while orthogonal arrays ensure a balanced set of experiments that allow simultaneous examination of multiple factors.

The present work, the objective is to identify the optimal combination of spindle speed, feed rate, depth of cut, and nose radius for Lathe machining of medium carbon alloy. The goal is to minimize surface roughness and determine the most significant process parameters through ANOVA analysis. By applying the Taguchi method, the best parametric combination is found using the S/N ratio, ensuring that the process yields minimal variation and high-quality results. [7].Controlling the cutting tool's vibration is one way to enhance the surface finish. cutting parameters, cutting depth, work piece speed, and vibrations of the cutting tool during manufacturing. Optimizing the speed, feed, and depth of cut will minimize vibration and enhance the surface smoothness of the final product [8].In this work, an attempt has been made to investigate the effects of process factors on surface roughness when turning commercially available lead alloy [9].Temperatures and tool behavior were investigated under various situations. The ISO3685 rules [10] were followed for conducting the studies.to decrease frequency after turning and enhance surface roughness [11]. In order to determine the optimal cutting parameters for a superior surface quality, vibration analysis using FFT (Fast Fourier Transform) was used to analyse the vibrations of both HSS and carbide-tipped single-point cutting tools [12].

## 2. Experiment details

The experiment was performed with turning of EN08 material for surface roughness. EN08 rod was cut 50 mm length per piece and 250 mm diameter used for turning operation. The cutting parameters are shown in table 3. The level of spindle speed, feed rate, nose radius and depth of cut four levels used are shown in table 4. The L16 orthogonal array is selected as per standard suggested Taguchi approach. The base material chemical composition is given in the table 1.

Table1: composition of EN8 alloy steel

| Elements | C | Si | P | Mn | Mo | Ni | S | Fe |
|---|---|---|---|---|---|---|---|---|
| Wt.% | 0.40 | 0.3 | 0.05 | 0.74 | 0.001 | 0.005 | 0.05 | Balance |

Fig1: Medium carbon alloy work piece

Fig2: Tool insert used in turning operation

i- Selection of parameters and levels

The process parameters which are to be optimized were set in levels in the machine range. Each parameter had 4 levels. The effects of these parameters were considered for evaluation effective response. The process parameters with their respective level are shown in table 2.

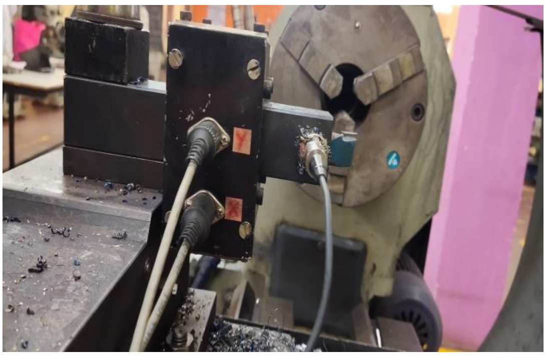

Fig3: Lathe machine tool

Fig 4: Machining Work pieces

Table 2: Process parameters and levels.

| Parameter s | L1 | L 2 | L3 | L4 |
|---|---|---|---|---|
| Cutting speed m/min | 100 | 150 | 200 | 250 |
| Feed rate mm/rev | 0.08 | 0.16 | 0.24 | 0.32 |
| Depth of cut mm | 0.20 | 0.40 | 0.60 | 0.80 |
| Nose radious mm | 0.4 | 0.8 | 1.2 | 1.4 |

ii. Selection of Orthogonal Array

Orthogonal array means the combination of parameters which should be taken while experimenting such that result yields same confidence as if all possible combinations will be taken. For different number of parameters and their levels Taguchi has suggested different orthogonal arrays. Here in this experiment 4 control variable (Nose radius, cutting speed, depth of cut, and feed rate) each having 4 levels was taken. Taguchi methodology this experiment will be perfectly done by taking L16 orthogonal array. Taguchi orthogonal array select by using Minitab 17 statistical software.


Fig 5: Surface roughness tester

iii- Experiment Procedure

Taguchi analysis is performed according to the selected design of experiment table. The minimum surface roughness developed in each set of combination are noted and tabulated in table. For each experiment the orthogonal array, signal to noise ratio(S/N) are calculated. The quality response is mainly divided into three categories; the smaller is better, larger is better and nominal is better. Smaller-the-better' S/N = -10*log (∑ (Y2 )/n) (1) Larger-the-better' S/N = -10*log (∑ (1/Y2 )/n) (2) Nominal-the-better' S/N= -10*log (S2 ) (3) Where y is the measured data y is the average data s is the variance of y and n is the number of samples. For

iv. Surface Roughness Measurement

There are many method is used to measure surface roughness, such as fingertip, microscopes, stylus type instrument, profile tracing instruments etc. The surface roughness tester SJ- 201P is a shop- floor type surface roughness measuring instrument used in present work. The measured values of the surface roughness are shown in table 3. delta values it assigns the rank to each which is having more influence on the mean of surface roughness. From the results S/N ratio also it is observed that nose radius is the dominant factor for surface roughness

## 3. Results and Discussions

Table 3lists the results of 16 machining trials utilizing the Taguchi L16 array, including the primary cutting force and surface roughness values. The computed S/N ratio is also shown in this table. The goal of the machining experiments was to explore the effects of cutting speed, feed rate, and depth of cut on surface roughness and primary cutting force. Using analysis of variance, the experimental data is processed of Surface roughness and response variables of principal cutting force. ANOVA is utilized to evaluate the impact of process characteristics derived from the HSS cutting tool machining evaluations. The Minitab-21 software is used to analyse the data. In the analysis of variance table, the sum of squares and degrees of freedom (DOF) are included.

Table 3: Taguchi's L16 Orthogonal Array with data

| Sl. No. | Vc (m/min) | DOC (mm) | FR (mm/rev) | Nose radious (mm) | SR (µm) | SNRA1 | MEAN1 |
|---|---|---|---|---|---|---|---|
| 1 | 100 | 0.08 | 0.20 | 0.4 | 2.784 | -8.8934 | 2.784 |
| 2 | 100 | 0.16 | 0.40 | 0.8 | 3.432 | -10.7109 | 3.432 |
| 3 | 100 | 0.24 | 0.60 | 1.2 | 3.672 | -11.2981 | 3.672 |
| 4 | 100 | 0.32 | 0.80 | 1.4 | 3.683 | -11.3240 | 3.683 |
| 5 | 150 | 0.08 | 0.40 | 1.2 | 1.164 | -1.3191 | 1.164 |
| 6 | 150 | 0.16 | 0.20 | 1.4 | 0.984 | 0.1401 | 0.984 |
| 7 | 150 | 0.24 | 0.80 | 0.4 | 1.536 | -3.7278 | 1.536 |
| 8 | 150 | 0.32 | 0.60 | 0.8 | 1.636 | -4.2757 | 1.636 |
| 9 | 200 | 0.08 | 0.60 | 1.4 | 0.744 | 2.5685 | 0.744 |
| 10 | 200 | 0.16 | 0.80 | 1.2 | 0.876 | 1.1499 | 0.876 |
| 11 | 200 | 0.24 | 0.20 | 0.8 | 1.02 | -0.1720 | 1.020 |
| 12 | 200 | 0.32 | 0.40 | 0.4 | 1.08 | -0.6685 | 1.080 |
| 13 | 250 | 0.08 | 0.80 | 0.8 | 0.534 | 5.4492 | 0.534 |
| 14 | 250 | 0.16 | 0.60 | 0.4 | 0.676 | 3.4011 | 0.676 |
| 15 | 250 | 0.24 | 0.40 | 1.4 | 0.984 | 0.1401 | 0.984 |
| 16 | 250 | 0.32 | 0.20 | 1.2 | 0.996 | 0.0348 | 0.996 |

Table 4: Response for Signal to Noise Ratios

| Level | Cutting Speed (m/min) | Depth of Cut (mm) | Feed Rate (mm/rev) | Nose Radius (mm) |
|---|---|---|---|---|
| 1 | -10.5566 | -1.5050 | -2.2226 | -2.4722 |
| 2 | -2.2956 | -3.7644 | -3.1396 | -2.4274 |
| 3 | 0.7195 | -4.0583 | -2.4010 | -2.8581 |
| 4 | 2.2563 | -0.5487 | -2.1132 | -2.1188 |
| Delta | 12.8129 | 3.5097 | 1.0264 | 0.7393 |
| Rank | 1 | 2 | 3 | 4 |

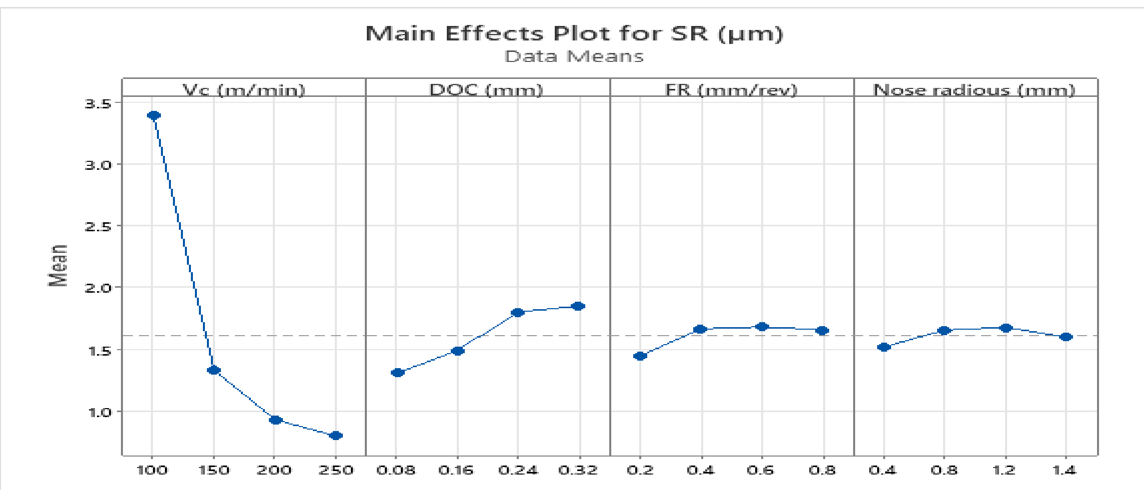


Fig 6: Cutting parameters effect on surface roughness

This main effects plot for surface roughness (SR) shows fig 6. How various machining parameters impact the mean surface roughness. The surface roughness decreases significantly as the cutting speed increases from 100 m/min to 200 m/min. Beyond 200 m/min, the surface roughness remains relatively stable. This suggests that increasing cutting speed up to 200 m/min improves the surface finish. The depth of cut shows an increasing trend in surface roughness as it increases from 0.08 mm to 0.32 mm. This indicates that a higher depth of cut leads to rougher surfaces. The effect of nose radius on surface roughness is minimal, as the mean values remain relatively consistent across different nose radius levels from 0.4 mm to 1.4 mm.

Table5: Analysis of Variance for surface roughness

| Source | DF | Seq SS | Contribution | Adj SS | Adj MS | F-Value | P-Value |
|---|---|---|---|---|---|---|---|
| Regression | 4 | 14.2574 | 76.82% | 14.2574 | 3.5644 | 9.11 | 0.002 |
| Vc (m/min) | 1 | 13.4013 | 72.20% | 13.4013 | 13.4013 | 34.26 | 0.000 |
| DOC (mm) | 1 | 0.7510 | 4.05% | 0.7510 | 0.7510 | 1.92 | 0.193 |
| FR (mm/rev) | 1 | 0.0847 | 0.46% | 0.0847 | 0.0847 | 0.22 | 0.651 |
| Nose radious (mm) | 1 | 0.0204 | 0.11% | 0.0204 | 0.0204 | 0.05 | 0.823 |
| Error | 11 | 4.3033 | 23.18% | 4.3033 | 0.3912 | | |
| Total | 15 | 18.5607 | 100.00% | | | | |

Table 5 shows the model has a total contribution of 76.82%, indicating that the selected parameters explain a significant portion of the variability in surface roughness. The model's F-value is 9.11 with a P-value of 0.002, indicating that the regression model is statistically significant at a 95% confidence level ($P < 0.05$). Cutting speed contributes 72.20% to the total variation, making it the most significant factor affecting surface roughness. It has an F-value of 34.26 and a P-value of 0.000, which shows that the effect of cutting speed on surface roughness is highly significant. The depth of cut contributes 4.05% to the variability in surface roughness. It has an F-value of 1.92 and a P-value of 0.193, indicating that its effect is not statistically significant at the 95% confidence level. The contribution of nose radius is 0.11%, indicating an almost negligible effect on surface roughness. The F-value of 0.05 and P-value of 0.823 confirm that it is not statistically significant. The error term contributes 23.18%, showing that there is still a notable portion of unexplained variability in the model, which could be due to factors not included in the study or experimental variability.

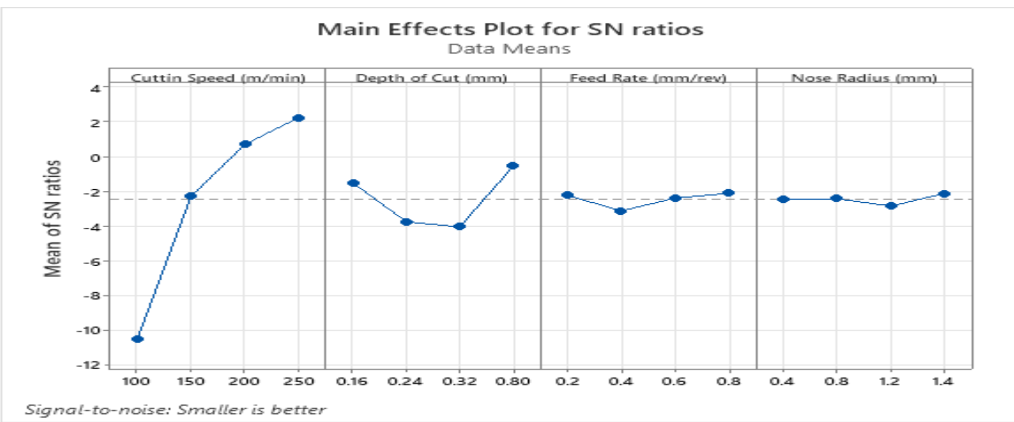


Fig 7: Cutting parameters effect on S/N ratio.

This main effects plot for S/N (signal-to-noise) ratios shows fig 7 how different machining parameters affect the S/N ratio for surface roughness, with the objective being "smaller is better" for optimal results Cutting Speed is the most influential factor on the S/N ratio, with higher speeds (up to 250 m/min) leading to better surface roughness (as indicated by the improved S/N ratio). Depth of Cut, Feed Rate, and Nose Radius have smaller impacts on the S/N ratio, showing relatively flat or fluctuating trends each type of the characteristic with the above S/N ratio transformation the higher the S/N ratio the better is the result. Minitab 17 statistical software used to calculate S/N ratios for each factor are shown in table 4.

## 4. Conclusions

Based on the ANOVA results and main effects plots, the following conclusions can be drawn regarding the surface roughness in the turning operation:

1. Cutting speed is the most influential factor for surface roughness, contributing 72.20% to the total variation. It has a highly significant impact, as shown by an F-value of 34.26 and a P-value of 0.000. Higher cutting speeds result in better surface finishes, as seen in the main effects plot.

2. The depth of cut contributes 4.05% to the surface roughness but is not statistically significant (P-value 0.193).

3. Feed rate contributes only 0.46%, and nose radius contributes 0.11% to the surface roughness, both showing negligible impact on the response. Their P-values (0.651 for feed rate and 0.823 for nose radius) confirm their non-significance.

4.The overall model is significant, with 76.82% of the variation in surface roughness explained by the four machining parameters. The regression model's P-value (0.002) indicates that the combination of parameters has a statistically significant effect on surface roughness

5. The study demonstrates that cutting speed plays a dominant role in achieving a smooth surface finish, followed by the feed rate, while the depth of cut has a relatively minor influence.

Declaration of Competing Interest

The authors insist that none of the work described in this publication may have been influenced by any known conflicting financial interests.

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