# Optimization of Process Parameters for Surface Roughness and Material Removal Rate for SS 316 on CNC Turning Machine

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**Abstract:**
*Efficient turning of high performance SS 316 austenite steel material can be achieved through proper selection of turning process parameters to minimize surface roughness and maximize material removal rate. In this present paper outlines an experimental study to optimize and study the effects of process parameters in CNC turning on Surface roughness and material removal rate of SS 316 (austenite steel) work material in dry environment conditions using physical vapour deposition (PVD) coated ceramic insert with 0.8mm nose radius and 80°negative rhombic angle. The full factorial method and analysis of variance are employed to study the performance characteristics in CNC turning operation. Three machining parameters are chosen as process parameters: Cutting Speed, Feed rate and Depth of cut. The experimentation plan is designed using design of experiment, L27 orthogonal array and Minitab-16 statistical software is used. Optimal values of process parameters for desired performance characteristics are obtained by analysis of variance (ANOVA). Prediction models are developed with the help of grey relational analysis method using Minitab-16 software and finally the optimal and predicted results are also verified with the help of confirmation experiments.*

**Keywords**: *ANOVA, CNC turning machine, Grey relational analysis, Material removal rate, Surface roughness*

## 1. Introduction

In machining process, Surface finish is one of the most significant technical requirements of the customer. A reasonably good surface finish is desired to improve the tribological properties, fatigue strength, corrosion resistance and aesthetic appeal of the product. Nowadays, manufacturing industries specially concerned to dimensional accuracy and surface finish. H. Yanda, et al. (2010) has investigated, optimum Ra and MRR are obtained at highest level of cutting speed, whereas the optimum value of a given control factor tool life is lower level of cutting speed. Anyway, the optimum condition for MRR is resulted at cutting speed of 360 m/min, feed rate of 0.5 mm/rev. The optimum surface roughness is resulted at cutting speed of 360 m/min, feed rate of 0.2 mm/rev, and for the optimum tool life is resulted at cutting speed of 220 m/min, feed rate of 0.2 mm/rev. M. Naga Phani Sastry and. K. Devaki Devi (2011) has found that feed and depth of cut have more significant effect while speed has less significant effect on MRR and feed and depth of cut has equal significance on surface roughness (Ra). M.

Kaladhar, et al. (2012) observed that feed plays an important role in both minimization of surface roughness and maximization of MRR. The ANOVA and F-test revealed that the feed is the dominant parameter followed by nose radius for surface roughness. In case of MRR response, the depth of cut is the dominant one followed by the feed.

The aim of this experimental investigation is to evaluate the effects of the process parameters on AISI 316 austenitic stainless steel work piece surface roughness and material removal rate by employing design of experiment using $L_{27}$ array and Analysis of Variance (ANOVA) using PVD coated Cermets tool on CNC lathe under dry environment. The AISI 316 austenitic stainless steel is the most widely used grade among the other grades of austenitic stainless steel. It is used for aerospace components and chemical processing equipment, for food, dairy, and beverage industries, for heat exchangers, and for the milder chemicals.

## 2. Design of Experiment

Design of experiments was developed in the early 1920s by Sir Ronald Fisher at the Rothamsted Agriculture field Research Station in London, England. His initial experiments were concerned with determining the effect of various fertilizers on different plots of land. The final condition of the crop was not only dependent on the fertilizer but also on the number of other factors (such as underlying soil condition, moisture content of the soil, etc.) of each of the respective plots. Fishers used DOE which could differentiate the effect of fertilizer and the effect of other factors. Since that time the DOE has been widely accepted in agricultural as well as Engineering Science. Design of experiments has become an important methodology that maximizes the knowledge gained from experimental data by using a smart positioning of points in the space. This methodology provides a strong tool to design and analyze experiments; it eliminates redundant observations and reduces the time and resources to make experiments.

We have used factorial design, and used **full factorial design**. For a full factorial design, if the numbers of levels are same then the possible design N is

$$N = L^m \qquad \dots (1)$$

Where, L = number of levels for each factor, and m= number of factors.

### *2.1 DOE for CNC Turning*

#### *2.1.1 Factors and their levels in CNC Straight Turning*

**Table 1 Factors and their levels in CNC straight turning**

| Process parameter | Process designation | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Cutting speed (m/min) | A | 95 | 110 | 125 |
| Feed (mm/rev) | B | 0.1 | 0.2 | 0.3 |
| Depth of cut (mm) | C | 0.7 | 1.4 | 2.1 |

From the above table according to design of experiments with full factorial design total numbers of experiments to be performed are 27.

**Table 2 Data obtained from experimental work for surface roughness**

| Cutting speed (m/min) | Cutting speed(rpm) | Feed (mm/rev) | Depth of cut (mm) | Surface roughness (µm) | MRR ($mm^3$/min) |
|---|---|---|---|---|---|
| 95 | 673 | 0.1 | 0.7 | 0.73 | 6553.09 |
| 95 | 673 | 0.1 | 1.4 | 0.74 | 12899.09 |
| 95 | 673 | 0.1 | 2.1 | 0.79 | 19038 |
| 95 | 673 | 0.2 | 0.7 | 1.41 | 13106.19 |
| 95 | 673 | 0.2 | 1.4 | 1.56 | 25798.19 |
| 95 | 673 | 0.2 | 2.1 | 1.69 | 38076 |
| 95 | 673 | 0.3 | 0.7 | 1.57 | 19659.28 |
| 95 | 673 | 0.3 | 1.4 | 1.69 | 38697.28 |
| 95 | 673 | 0.3 | 2.1 | 1.70 | 57114 |
| 110 | 779 | 0.1 | 0.7 | 0.65 | 7585.23 |
| 110 | 779 | 0.1 | 1.4 | 0.74 | 14930.75 |
| 110 | 779 | 0.1 | 2.1 | 0.75 | 22036.85 |
| 110 | 779 | 0.2 | 0.7 | 1.08 | 15170.46 |
| 110 | 779 | 0.2 | 1.4 | 1.17 | 29861.5 |
| 110 | 779 | 0.2 | 2.1 | 1.09 | 44073.11 |
| 110 | 779 | 0.3 | 0.7 | 1.10 | 22755.69 |
| 110 | 779 | 0.3 | 1.4 | 1.26 | 44792.25 |
| 110 | 779 | 0.3 | 2.1 | 1.38 | 66109.65 |
| 125 | 885 | 0.1 | 0.7 | 0.49 | 8617.37 |
| 125 | 885 | 0.1 | 1.4 | 0.58 | 16962.41 |
| 125 | 885 | 0.1 | 2.1 | 0.65 | 25035.11 |
| 125 | 885 | 0.2 | 0.7 | 1.32 | 17234.74 |
| 125 | 885 | 0.2 | 1.4 | 1.23 | 33924.82 |
| 125 | 885 | 0.2 | 2.1 | 1.22 | 50070.22 |
| 125 | 885 | 0.3 | 0.7 | 1.37 | 25852.11 |
| 125 | 885 | 0.3 | 1.4 | 1.51 | 50887.23 |
| 125 | 885 | 0.3 | 2.1 | 1.48 | 75105.33 |

## 3. Experimental Set Up

In order to achieve the goal of this experimental work the cutting tests were carried out in a SUPERCUT 6N CNC turning center. The CNC turning centre has 5.5 kw / 7 kw spindle motor power and a maximal machining diameter of 165mm, maximal spindle speed of 4000 rpm, spindle speed range 40 to 4000 rpm and maximal turning length 350mm.

### *3.1 Work Piece Material:*

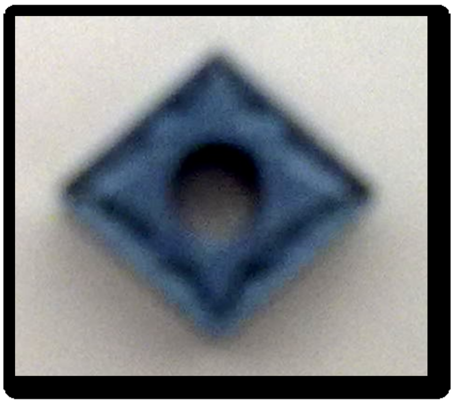
- Low alloy steel AISI 316 or SS316.
- Dimension for material is Ø45 X 35 mm.

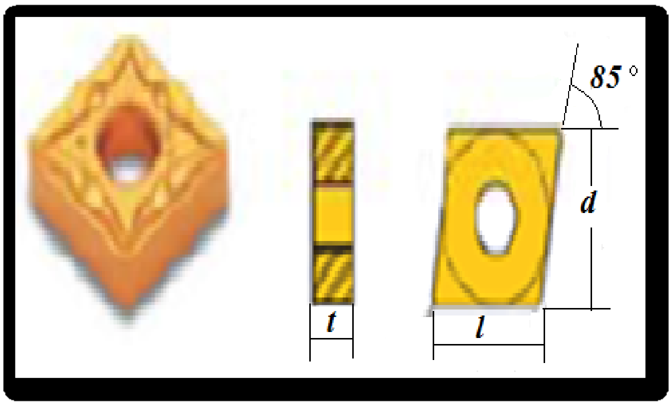
**Table 3 Chemical composition**

| Elements | C | Mn | Si | P | S | Cr | Mo | Ni | N |
|---|---|---|---|---|---|---|---|---|---|
| Wt.% | 0.08 | 2.0 | 0.75 | 0.045 | 0.03 | 16-18 | 2-3 | 10-14 | 0.10 |

***3.2 Selection of cutting tool and tool holder***

The cutting tool selected for present work is coated (TiN) carbides (Tungsten) inserts and Taegutec catalog is used for selection of cutting tool for machining stainless steel 316 grade. Based on the catalog, following type of insert (ISO coding) is used in present work CNMG 120408 MT TT 8020(PVD Coated).






**(a)** **(b)**

**Fig. 1 CNMG 120408 MT TT 8020 (PVD Coated) tool**

The tool geometry of the insert CNMG 120408 MT (PVD coated) - Rhombic 80º,insert clearance angle 0º (Negative),relief angle - 3º,cutting edge length-12mm,insert thickness-4mm,nose radius-0.8mm.M indicates heavy feed chip and T indicates negative land counter. According to Taegutec catalog, ISO coding tool holder TCLNL 2525M12 has been used for negative insert.

## 4. ANOVA Analysis

**Table 4 ANOVA for surface roughness**

| Parameter | Process Parameter | Variance | Test F | % of Contribution |
|---|---|---|---|---|
| A | Cutting Speed | 0.02182 | 17.7398 | 11.54% |
| B | Feed | 1.5172 | 123.3496 | 80.26% |
| C | Depth Of Cut | 0.0321 | 2.6097 | 1.7% |
| Error | | 0.0123 | 1 | 6.5% |

**Table 5 ANOVA for material removal rate**

| Parameter | Process Parameter | Variance | Test F | %of Contribution |
|---|---|---|---|---|
| A | Cutting Speed | 147004429.6 | 0.5348 | 3.43 |
| B | Feed | 1984924522 | 7.2213 | 46.31 |
| C | Depth Of Cut | 1879734962 | 6.8387 | 43.85% |
| Error | | 274869221.6 | 1 | 6.41% |

## 5. Main Effect Plots for ANOVA

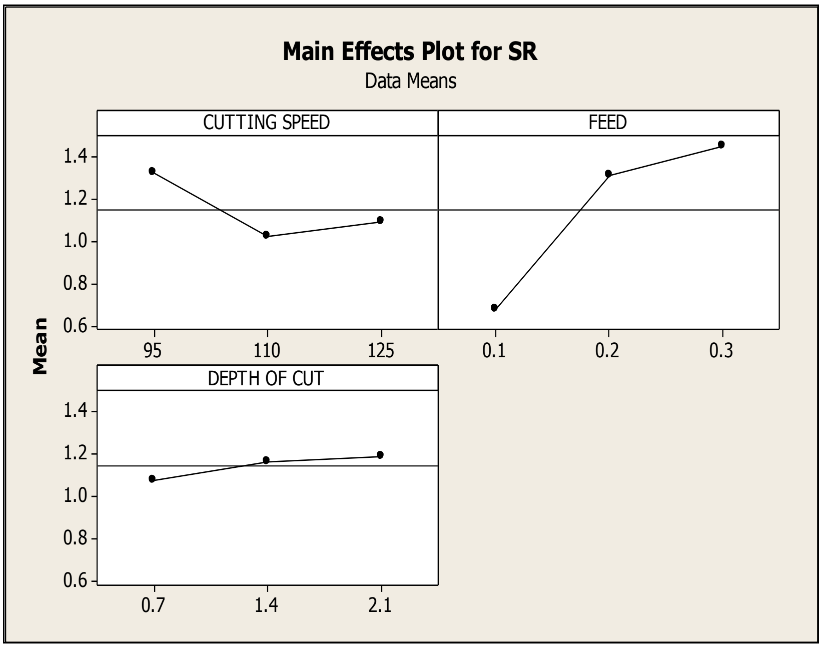



**Fig. 2 Main effect plot for Surface Roughness**

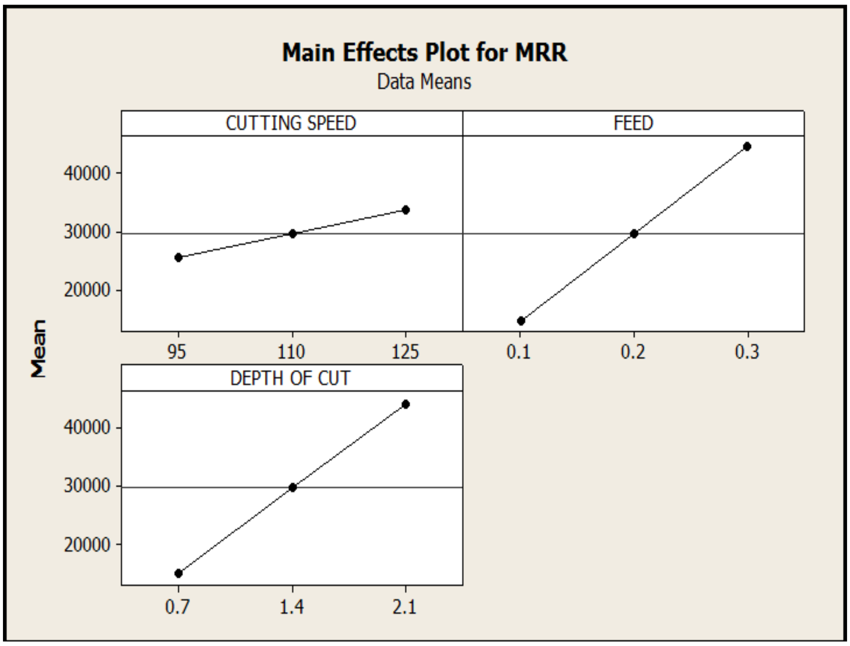



**Fig. 3 Main effect plot for Material removal rate**

## 6. Grey Relational Analysis

In grey relational generation, the normalized data corresponding to Lower-the-Better (LB) criterion can be expressed as:

$$Xi(k) = \frac{\max yi\,(k) - yi(k)}{\max yi(k) - \min yi(k)} \qquad \text{... (2)}$$

For Higher-the-Better (HB) criterion, the normalized data can be expressed as:

$$\mathrm{Xi(k)} = \frac{\mathrm{yi(k) - min\,yi\,(k)}}{\mathrm{max\,yi(k) - min\,yi(k)}} \qquad \ldots (3)$$

Where xi (k) is the value after the grey relational generation, min $yi\ (k)$is the smallest value of $yi\ (k)$for the $k_{th}$ response, and max $yi\ (k)$is the largest value of $yi\ (k)$for the $k_{th}$ response. An ideal sequence is $x_0$ (k) for the responses.

The purpose of Grey relational grade is to reveal the degrees of relation between the sequences say, [x0 (k) and xi (k), i = 1, 2, 3…, n]. The Grey relational coefficient can be calculated using the preprocessed sequences. The Grey relational coefficient $\xi i(k)$is defined as follows

$$\mathrm{\xi i(k)} = \frac{\mathrm{min\Delta + \theta max\Delta}}{\mathrm{\Delta i\ (k) + \theta max\Delta}}; \quad 0 \le \mathrm{\xi i(k)} \le 1 \qquad \ldots (4)$$

Where $\Delta i$=$|\mathrm{x0(k)} - \mathrm{xi(k)}|$ =difference of the absolute value x0 (k) and xi (k); θ is the distinguishing coefficient 0 ≤ θ ≤ 1; $min\Delta$= ∀j $min$∊i ∀k $min|\mathrm{x0(k)} - \mathrm{xj(k)}|$=the smallest value of Δ0i; and $max\Delta$= ∀j $max$∊i ∀k $max$= largest value of Δ0i. After averaging the grey relational coefficients, the grey relational grade γi can be computed as:

$$yi = \frac{1}{n}\sum_{k=1}^{n} \xi i\ (k) \qquad \ldots (5)$$

Where n = number of process responses. The higher value of grey relational grade corresponds to intense relational degree between the reference sequence x0 (k) and the given sequence xi (k). The reference sequence x0 (k) represents the best process sequence. Therefore, higher grey relational grade means that the corresponding parameter combination is closer to the optimal.

**Table 6 Grey relational analysis**

| Experiment No. | Normalize value of SR | Normalize value of MRR | GRC of SR | GRC of MRR | GRG | Grade No. |
|---|---|---|---|---|---|---|
| 1 | 0.8016529 | 0 | 0.715976 | 0.333333 | 0.524655 | 10 |
| 2 | 0.7933884 | 0.092572 | 0.707602 | 0.355258 | 0.53143 | 9 |
| 3 | 0.7520661 | 0.182123 | 0.668508 | 0.379398 | 0.523953 | 11 |
| 4 | 0.2396694 | 0.095593 | 0.396721 | 0.356022 | 0.376372 | 26 |
| 5 | 0.0991736 | 0.280736 | 0.356932 | 0.410084 | 0.383508 | 25 |
| 6 | 0.0082645 | 0.459838 | 0.33518 | 0.480694 | 0.407937 | 23 |
| 7 | 0.107438 | 0.191185 | 0.35905 | 0.382025 | 0.370538 | 27 |
| 8 | 0.0082645 | 0.468901 | 0.33518 | 0.484919 | 0.41005 | 21 |
| 9 | 0 | 0.737553 | 0.333333 | 0.655783 | 0.494558 | 14 |
| 10 | 0.8677686 | 0.015056 | 0.79085 | 0.336713 | 0.563781 | 6 |
| 11 | 0.7933884 | 0.122208 | 0.707602 | 0.3629 | 0.535251 | 8 |
| 12 | 0.785124 | 0.225868 | 0.699422 | 0.392424 | 0.545923 | 7 |
| 13 | 0.5123967 | 0.125705 | 0.506276 | 0.363823 | 0.43505 | 20 |
| 14 | 0.4380165 | 0.340009 | 0.470817 | 0.431038 | 0.450928 | 19 |
| 15 | 0.5041322 | 0.54732 | 0.502075 | 0.524835 | 0.513455 | 13 |
| 16 | 0.4958678 | 0.236354 | 0.497942 | 0.39568 | 0.446811 | 18 |
| 17 | 0.3636364 | 0.557811 | 0.44 | 0.530679 | 0.485339 | 15 |
| 18 | 0.2644628 | 0.868776 | 0.404682 | 0.792112 | 0.598397 | 5 |
| 19 | 1 | 0.030113 | 1 | 0.340162 | 0.670081 | 2 |

| Experiment No. | Normalize value of SR | Normalize value of MRR | GRC of SR | GRC of MRR | GRG | Grade No. |
|---|---|---|---|---|---|---|
| 20 | 0.9256198 | 0.151845 | 0.870504 | 0.370877 | 0.62069 | 3 |
| 21 | 0.8677686 | 0.269605 | 0.79085 | 0.406374 | 0.598612 | 4 |
| 22 | 0.3140496 | 0.155818 | 0.421603 | 0.371973 | 0.396788 | 24 |
| 23 | 0.3884298 | 0.399283 | 0.449814 | 0.454249 | 0.452032 | 17 |
| 24 | 0.3966942 | 0.634802 | 0.453184 | 0.577903 | 0.515543 | 12 |
| 25 | 0.2727273 | 0.281523 | 0.407407 | 0.410348 | 0.408878 | 22 |
| 26 | 0.1570248 | 0.646721 | 0.372308 | 0.585974 | 0.479141 | 16 |
| 27 | 0.1818182 | 1 | 0.37931 | 1 | 0.689655 | 1 |

**Table 7 ANOVA for grey relational grade**

| Source | Degree of freedom DF | Sum of Square SS | Adj SS | Adj MS | Variance ratio F | P |
|---|---|---|---|---|---|---|
| Cutting speed | 2 | 0.037924 | 0.037924 | 0.018962 | 6.82 | 0.006 |
| Feed rate | 2 | 0.079163 | 0.079163 | 0.039581 | 14.24 | 0.000 |
| Depth of cut | 2 | 0.029575 | 0.029575 | 0.014788 | 5.32 | 0.014 |
| Error | 20 | 0.055608 | 0.055608 | 0.002780 | | |
| Total | 26 | 0.202270 | | | | |
| S = 0.0527293 | | | R-Sq = 72.51% | | R-Sq (adj) = 64.26% | |

## 7. Regression equation

**For Surface Roughness**
SR = 1.09667 - 0.00759259 Cutting Speed + 3.85556 Feed + 0.081746 Depth of Cut

**For Material Removal Rate**
MRR = -58540.8 + 269.438 Cutting Speed + 148508 Feed + 20644.8 Depth of Cut

**For Grey Relational Grade**
GRG = 0.17202 + 0.00299415 Cutting Speed - 0.406116 Feed + 0.0551651 Depth of Cut

## 8. Result and Conclusion

In this dissertation work, various cutting parameters like, cutting speed, feed and depth of cut have been evaluated to investigate their influence on surface roughness and material removal rate. Based on the result obtained, it can be concluded as follows:

**Surface Roughness**

- Cutting speed, feed rate and depth of cut significantly effects on surface roughness.

- Feed rate is found the most significant effect on surface roughness. Increase in feed rate, value of surface roughness is increase.
- Cutting speed is found to have effect on surface roughness. Increase in cutting speed, value of surface roughness is decrease.
- Depth of cut is found to have effect on surface roughness. Increase in depth of cut value of surface roughness is increase.
- The optimal combination of low feed rate and low depth of cut with high cutting speed is beneficial for reducing machining force so surface roughness is decrease when high cutting speed, low feed rate and low depth of cut.
- The percentage contribution of cutting speed is 5.29 %, feed of 86.13 % and depth of cut of 3.27 % on surface roughness.
- From the ANOVA it is conclude that the feed rate is most significant parameter which contributes more to surface roughness.

**Material Removal Rate**

- The volume of material removed can be achieved better when machining was done at high depth of cut and high feed rate.
- Depth of cut is found the most significant effect on material removal rate. Increase in depth of cut, value of material removal rate is increase.
- The percentage contribution of cutting speed is 5.57 %, feed of 46.40 % and depth of cut of 43.02 % on material removal rate.
- In multi response optimization the optimum parameter combination is meeting at experiment 3 and its parameter value is 1.4 mm depth of cut, 125 m/min cutting speed and 0.1 mm/rev feed rate.
- From the ANOVA it is conclude that the depth of cut is most significant parameter which contributes more to material removal rate.

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