Optimisation of Quality and Prediction of Machining Parameter for Surface Roughness in CNC Turning on EN8

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Abstract

Objective: Effect of machining parameter (Speed, Feed, Depth of cut) on output machine responses (Material Removal Rate (MRR), Machining time, Tool wear and Surface roughness) is studied using Taguchi method. Methods/Analysis: Experiment was conducted on work piece material namely EN8 Steel. For cutting speed, feed rate, Depth Of Cut (DOC). Orthogonal array L9 was created using MINITAB-16. For different combination, the respective surface roughness average was obtained using surface roughness tester and Taguchi analysis to understand the relation between the machining parameters and output responses. Findings: Feed rate is the important factor in obtaining the optimum surface finish of EN8 than other parameters during turning and also scars can be reduced gradually. Novelty/Improvement: With the help of Taguchi method, Noise factor and control factor are identified which are highly useful in screening the critical parameters for optimum surface finish.

Keywords: Machining parameter, Optimisation, Surface Roughness, Taguchi Method, Turning

1. Introduction

Turning is the removal of metal from the outer diameter of a rotating job. Hard turning is considered as a new machining process aimed at turning hardened steel with high metal removal rate, good finish as well as less tool wear. Quality depends only on production according to traditional concept whereas it depends on all phases from design to after-sales service in modern concept. Hard turning is the latest improvement in manufacturing industries and it is productive alternative to the grinding. In EN8 as work piece and Tungsten Carbide insert as cutting tool in CNC lathe machine. The Surface parameter used to study Surface roughness in this study is the roughness average (Ra). Since 1960, Taguchi method have been used for improving Japanese products’ quality and from 1980’s, it practised to wide part of the world. To attain good product quality by design, Taguchi suggested a three stage process: System design, Parameter design, and Tolerance design. System design is the conceptualisation and synthesis of a product or process to be used. Parameter design is related to finding the appropriate design factor levels to make the system less sensitive to variation in uncontrollable factors i.e. to make the system robust. Tolerance design occurs when the tolerance for the products or process is created to minimise the sum of the lifetime costs and manufacturing costs. Thus we decided to optimise the machine parameter using Taguchi method and ANOVA in order to get optimal process parameter and study how it affects the machining parameter. ANOVA suggests the depth of cut is the most
important factor for both surface roughness and MRR and feed is the significant factor for surface roughness and spindle speed for Material Removal Rate (MRR)\(^2\).

### 2.1 Design of Experiment

Experimental design methods are very complex and not easy to use when conducted practically. Beside this, a number of experiments have to be carried out when the number of the process parameters increases, to solve this complication. Experiment was conducted in RSM and GA to determine machining parameter in steel already\(^3\).

In\(^4\), Taguchi method to obtain optimal control factor and percentage of contribution by the process parameters. In design of experiment, Process parameters and their level responses for all noise factors for the given factor level combination are given in the Table 1. By using MINITAB – 16 Software, the turning parameters have been optimized.

| SPEED  | FEED  | DOC  |
|--------|-------|------|
| 1500   | 0.02  | 0.25 |
| 1750   | 0.04  | 0.50 |
| 2000   | 0.06  | 0.75 |

### 2.2 Design of Orthogonal Array

Taguchi Orthogonal array is designed in MINITAB-16 to calculate S/N ratio and Create Taguchi Design as shown in the Figure 1.

### 2.3 Experimental Set up

The schematic representation of the purpose of the experiment is as shown in the below Figure 2.

### 2.4 Experimental Procedure

The experiment was conducted using work piece material namely EN 8 steel with tungsten carbide tool inserts manufactured by ceratizit. The test was carried out for a length of 60 mm, 32 mm diameter in CNC turning centre. The machine is having feed rate in revolution per minute. 3 level of cutting speed ,3 level of feed rate and 3 level of depth of cut and 1 level insert radius were used as per the orthogonal array created using MINITAB-16 as shown in the Table 2 as below. 9 work pieces were used for 9 different value for Speed, feed, depth of cut combinations and the respective Roughness Average value were obtained using the Surface Roughness tester.

### 2.4.1 An Orthogonal Array L9 Formation

An orthogonal array L9 is formed as show in the Table 3 below with the help of MINITAB 16, Ref to Figure 1.

Table 2. An orthogonal array L9 formation.
| TRIAL NO. | DESIGNATION | Speed | Feed | DOC |
|-----------|-------------|-------|------|-----|
| 1         | A, B, C₁    | 1500  | 0.02 | 0.25|
| 2         | A, B, C₂    | 1500  | 0.04 | 0.50|
| 3         | A, B, C₃    | 1500  | 0.06 | 0.75|
| 4         | A, B, C₄    | 1750  | 0.02 | 0.50|
| 5         | A, B, C₅    | 1750  | 0.04 | 0.75|
| 6         | A, B, C₆    | 1750  | 0.06 | 0.25|
| 7         | A, B, C₇    | 2000  | 0.02 | 0.75|
| 8         | A, B, C₈    | 2000  | 0.04 | 0.25|
| 9         | A, B, C₉    | 2000  | 0.06 | 0.50|

After forming the orthogonal array, the machining is done for each of the 9 different combination of Speed, Feed, DOC on 9 job of EN 8 in CNC lathe machine.

2.4.2 S/N Ratio for Surface Roughness, Machine Timing, MRR

S/N ratio for Surface roughness (Ra), Machine timing, Material Removal Rate are calculated using Taguchi method in MINITAB-16 as illustrated below step by step manner in the following Figure 3(a), 3(b), 3(c), 3(d), 3(e).

The following are the steps to obtain S/N ratio for Surface Roughness (Ra), Machine timing, Material Removal Rate:

**Step 1**: Select available design as shown in the Figure 3(a).

**Step 2**: Then click on ‘design’ menu and select ‘L9’ then press ‘OK’ as in the Figure 3(b) to select Taguchi design.

**Step 3**: Click on “Factor” and write the name of the factor and levels of the factor as desired as shown in the Figure 3(c) and press “OK” to analyse Taguchi design option for each machine parameters.

**Step 4**: Give input response in the Taguchi design factor dialog box as shown in the Figure 3(d).
Step 5: Finally Press “OK” to analyse the input Taguchi design, then Graph and S/N ratio are generated for corresponding factors as shown in the Figure 3(e) And this process will continue for each process parameter as the constraints varies, S/N ratio also get varies. Then, the final calculation is done based on the input from experiment data calculated and S/N ratio calculated using MINITAB-16, to predict the contribution percentage of each machining parameter and to obtain the ideal combination of Speed, Feed, DOC using ANOVA.

2.5 Calculations

The experimental data has been tabulated as shown in the Table 3, based on the machining of 9 machine jobs as per the combination of orthogonal array created. Then S/N ratio and ANOVA for each machine parameter – Machine timing, Surface roughness and MRR.

2.5.1 Machine timing (Analysis of Result)

Taguchi Analysis and Analysis of variance (ANOVA): Machining time Vs Speed, Feed, DOC

Based on the output from MINITAB-16, Response Table pertaining to S/N Ratio (Smaller is better) and mean values are tabulated as in the Figure 4, corresponding ranking has been done to obtain effect plots of main, for S/N Ratio, means as in the Figure 5.

![Figure 4](image)

**Figure 4.** (Left) Response table for S/N ratio and means- machine timing vs speed, feed and DOC. (Right) ANOVA table - general linear model: Machining time vs speed, feed, depth of cut. (Screen Shot: Output from MINITAB’16).

Analysis of Variance is done to find the percentage of contribution by machining time to Speed, Feed, and Depth of Cut as shown in ANOVA Figure 4. From ANOVA table, it is inferred that contribution of Machining time to Feed is maximum (38.4%), compared to Speed (35.5%) and Depth of Cut (6.2%).

2.5.2 Surface Roughness (Analysis of Result)

Taguchi Analysis & Analysis of variance (ANOVA): Surface Roughness Vs Speed, Feed, DOC

Similar to Analysis of result for Machining time, Taguchi Analysis and ANOVA for Surface roughness is done. Based on the output from MINITAB-16, Response Table for S/N Ratio and means are tabulated as in the Figure 6, and corresponding ranking has been done to obtain main effect plots for S/N Ratio and means as in the Figure 7. From the above ANOVA table in the Figure 6, it is inferred that contribution of Surface Roughness to Speed (38.5%) is maximum compared to Feed (30.2%) and Depth of Cut (15.15%).
Taguchi Analysis and ANOVA for Surface roughness is also done and based on the output from MINITAB-16, Response Table for the values of S/N Ratio and mean values are tabulated as in the Figure 8, and corresponding ranking has been done to obtain main effect plots for S/N Ratio and means as in the Figure 9. Here in Material Removal Rate, S/ N ratio is considered for ‘Larger the better’ since higher the rate of removal of material is considered desirable whereas in Machine Time and Surface Roughness ‘Smaller the better’ is considered as productive.

2.5.3 Material Removal Rate (Analysis of Result)

Taguchi Analysis & Analysis of variance (ANOVA): MRR Vs Speed, Feed, DOC.

From the ANOVA table in the Figure 8, it is inferred that contribution of Material Removal Rate to Feed is maximum (54.4%), compared to Speed (35.2 %) and Depth of Cut (5.45%).

3. Summary and Result

In this study, the Taguchi technique and ANOVA were used to obtain ideal turning parameters in the turning of EN8. As a result of the Taguchi experimental iterations, it was found that the feed rate is the most important factor improving the Surface Roughness, machining time.
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The experimental results were decided using ANOVA, Optimal control factor are obtained as below and Percentage of contribution of process parameters are also tabulated as shown in the Table 4:

3. Material Removal Rate- A2 (Speed-1750) B1 (Feed 0.02) C3 (DOC0.75.)

| Process Parameter     | Percentage of Contribution (in %) |
|-----------------------|-----------------------------------|
| Speed                 | 36.0                              |
| Feed                  | 38.4                              |
| Depth of Cut          | 6.2                               |

Table 4. Percentage of contribution of process parameters

4. Conclusion

The Series of Experimental trails conducted on EN8 and solving the Orthogonal array formed by means of Taguchi method, analysis of variance derive the following conclusion : (1) Feed rate is the most important deciding factor for obtaining optimum surface finish, Less Machining time, Higher Material Removal rate, than Speed, Depth of Cut (2) If optimum control factors combinations obtained are incorporated into machining , Optimum Surface roughness (Ra) value can be obtained and also scrap can get reduced considerably. (3) Both Taguchi method and ANOVA are less time consuming process so it can be applied for any turning operation, lathe operation to analyse the optimal control factors and also percentage of contribution of process parameters.

Table 3. Experimental data

| TRIAL NO. | DESIGNATION | Speed | Feed | DOC | Machining time | Ra   | MRR  |
|-----------|-------------|-------|------|-----|----------------|------|------|
| 1         | A B1 C3     | 400   | 0.02 | 0.25| 1.47           | 0.947| 1.02 |
| 2         | A B2 C2     | 400   | 0.04 | 0.50| 1.36           | 0.452| 1.16 |
| 3         | A B2 C3     | 400   | 0.06 | 0.75| 1.12           | 0.854| 1.56 |
| 4         | A B1 C2     | 600   | 0.02 | 0.50| 1.34           | 0.194| 1.18 |
| 5         | A B2 C3     | 600   | 0.04 | 0.75| 0.38           | 0.428| 2.09 |
| 6         | A B C3      | 600   | 0.06 | 0.25| 1.23           | 0.656| 2.89 |
| 7         | A B C3      | 800   | 0.02 | 0.75| 1.23           | 0.336| 1.34 |
| 8         | A B C3      | 800   | 0.04 | 0.25| 0.47           | 0.376| 2.36 |
| 9         | A B1 C3     | 800   | 0.06 | 0.50| 0.36           | 0.659| 3.16 |

Figure 9. Main effects plot for S/N ratio and means- material removal rate vs speed, feed and depth of cut.

1. Surface Roughness- A1 (Speed -1500) B2 (Feed -0.04) C3 (DOC-0.75)
2. Machining Time - A1 (Speed -1500) B2 (Feed -0.04) C3 (DOC-0.75)
5. References

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