Optimization of turning process variables for surface integrity using taguchi technique

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Abstract. The selection of proper machining parameters is crucial for the production of a product of desired quality. The Taguchi method will accomplish this. For this work, using tin coated tungsten carbide method, SS-321 work parts are placed onto CNC lathe machine. Stainless steel machining (SS-321) has issues such as worn-out tool and high roughness to the surface. The key reasons for choosing SS-321 grade as workpiece material is the issue of the machining process related with super finishing of Stainless Steel. For this work twenty-seven experiments were carried out on stainless steel (SS-321), as per Taguchi’s L₂₇ orthogonal array. Data analysis was carried out using Taguchi response table method and ANOVA. Following this method, a confirmation experiment was performed to assess the surface integrity change. Turning machining parameter levels to reduce surface roughness were A₁B₃C₁ i.e., depth of cut 0.5 mm, cutting speed of 120 m/min and feed of 0.2 mm/rev. ANOVA table represented the parameters which mostly affected the surface roughness with 76.27% contribution of depth of cut which is maximum followed by feed (7.72%), and effect of speed (3.48%) is insignificant. The research also shows that this approach can efficiently boost the surface finish of the turning process.

1. Introduction

Surface roughness (SR) plays a vital role in various fields and plays an important role in evaluating processing accuracy [1]. Our main concern now is to reduce costs and time, improve quality and economic productivity. Better surface finish and less tool wear are a challenge when using materials with high strength, resistance to corrosion and resistance to wear while turning. Optimized cutting parameters should be employed to solve the above problems [2].

Turning is one of the excess metal removal methods used for machining. The metal removal is the removal of a piece of metal from the workpiece to produce a finished product with the desired lengths, shapes and characteristics of surface roughness. The task for engineers is to search the best parameters for the desired output, and optimize performance with the resources available [3]. Most of the components like rail road cars, mining, various kinds of vehicles etc. are constructed from machined SS-321. Siddiquee et al [4] conducted the experiments on SS-321 steel by taguchi method for optimizing deep drilling process parameters. Dhar et al. [5] submitted that the roughness of the SS-4340 surface decreases by using minimal lubrication. Sijo M.T et al. [6] concluded that optimization of the turning process parameter is time consuming and highly complex. During turning the cutting parameters were
optimized by taguchi techniques. Om Prakash Singh et al [7,8] proposed the taguchi and grey relational analysis for optimizing the shoulder milling parameters of AA 6063T6 Aluminium alloys.

A plethora of research on the impact of process parameters on surface roughness has been published in literature surveys. There is, however, little literature on the effect on SS-321 of the turning process parameters. Many researchers have noted that the taguchi approach and grey relationship analysis have become powerful tools for increasing productivity in the development process and have found a wide range of applications through different machining processes. High quality goods can therefore be manufactured easily and at low cost.

In this study 27 experiments were conducted by using taguchi for optimization of three turning parameters (depth of cut, speed and feed) for machining of SS-321 on CNC lathe machine for improving surface roughness.

2. Experimental Details

2.1 Work piece Material
Machined SS-321 material was used to perform experimental work. General purpose SS-321 has been chosen as the standard because it is most flexible and commonly used. SS-321 fragment samples used during testing are as shown in figure1 and the chemical constituents present in SS-321 are shown in table 1.

![Figure 1. Stainless steel (AISI-321) pieces](image)

| Elements     | Concentration (by weight%) | Concentration (by weight %) | Concentration (by weight %) |
|--------------|----------------------------|----------------------------|-----------------------------|
|              | Minimum                    | Maximum                    | Actual                      |
| Carbon       | 00.080                     | 00.070                     |                             |
| Manganese    | 2.000                      | 1.780                      |                             |
| Silicon      | 1.000                      | 1.000                      |                             |
| Phosphorus   | 00.045                     | 00.380                     |                             |
| Sulphur      | 00.030                     | 0.260                      |                             |
| Nickel       | 9.000                      | 12.000                     | 10.380                      |
| Chromium     | 17.000                     | 19.000                     | 17.200                      |
| Copper       | 0.750                      |                            | 00.380                      |
2.2 CNC Lathe Machine
The turning operations were performed on the SS-321 pieces by the CNC Lathe machine as shown in figure 2. Mitotoyo tester was used for testing the surface roughness as shown in figure 3.

![Figure 2. CNC lathe Machine](image1)

![Figure 3. Surface Roughness Tester](image2)

Different operating conditions for turning with their specifications are shown in table 2.

| Condition | Specification |
|-----------|---------------|
| Work piece material | SS-321 |
| Geometry of work piece | 50mm in dia. and 200mm in length |
| Turning machine | CNC Turning machine (Make: Taiwan in 2011 Model: Leadwell, T-6; Tool movement: X-150 mm, Z-350mm, and 5.5-KW/4500 rpm) |
| Cutter used | Tin coated solid carbide tool (nose radius 0.8mm) |
| Measuring tool | Mitotoyo surface roughness tester |

2.3 Experimental Design
The experimental work was carried out according to the experimental configuration of the L27 orthogonal array on a CNC turning machine. Optimal order of turning parameters for turning was obtained by using ANOVA. As shown in table 3, three key turning parameters i.e., doc, speed and feed and their levels were determined during machining.

| Factor identifier | Machining parameter | Level 1 | Level 2 | Level 3 |
|-------------------|---------------------|---------|---------|---------|
| A                 | Depth of Cut (mm)   | 0.5     | 1       | 1.5     |
| B                 | Speed (m/min.)      | 60      | 90      | 120     |
| C                 | Feed (mm/rev.)      | 0.2     | 0.25    | 0.3     |

3. Results and discussion
3.1 Analysis of Signal to Noise Ratio
In this study, equation one was used for minimization of surface roughness which is based on lower is the good criterion.

Lower-is-Good:

\[
S/N_{dB} = -10\log \left[ \frac{1}{m} \sum_{y=1}^{m} R_{xy}^2 \right]
\] (1)
Where, $R_{xy}$ is the value of surface roughness for $x^{\text{th}}$ observation at the $y^{\text{th}}$ test, $m$ is the number of total observations taken. Other formulae of Signal to Noise ratio calculations can be found in references [9, 10, 11]. Table 4 represents the S/N ratios for 27 experiments. Calculations of mean value ($\theta_i$) of S/N ratios was find out by equation 2 as given below [12,13,14].

$$\theta_i = \frac{1}{M} \sum_{j=1}^{M} \gamma(j)$$ (2)

Where $j=1,2,\ldots, M$ (here $M=27$) and $\gamma(j)$ is S/N ratio for $j^{\text{th}}$ experiment condition. From table 5 and figure 4 based on the maximum value of S/N ratio, an optimum level for each turning parameter was $A_1B_3C_1$ which means depth of cut 0.5 mm, speed 120 m/min and feed of 0.2 mm/rev. was noticed.

### Table 4. Values of S/N ratio

| Experiment No. | doc | speed | feed | Ra(μm) | S/N Ratio $\gamma(j)$ |
|----------------|-----|-------|------|--------|-----------------------|
| 1              | 1   | 1     | 1    | 1.57   | -3.918                |
| 2              | 1   | 1     | 2    | 0.92   | 0.724                 |
| 3              | 1   | 1     | 3    | 1.26   | -2.007                |
| 4              | 1   | 2     | 1    | 0.97   | 0.265                 |
| 5              | 1   | 2     | 2    | 1.285  | -2.178                |
| 6              | 1   | 2     | 3    | 1.11   | -0.906                |
| 7              | 1   | 3     | 1    | 0.645  | 3.809                 |
| 8              | 1   | 3     | 2    | 0.71   | 2.975                 |
| 9              | 1   | 3     | 3    | 0.8    | 1.938                 |
| 10             | 2   | 1     | 1    | 2.005  | -6.042                |
| 11             | 2   | 1     | 2    | 2.06   | -6.277                |
| 12             | 2   | 1     | 3    | 2.86   | -9.127                |
| 13             | 2   | 2     | 1    | 1.545  | -3.779                |
| 14             | 2   | 2     | 2    | 2.07   | -6.319                |
| 15             | 2   | 2     | 3    | 3.09   | -9.799                |
| 16             | 2   | 3     | 1    | 1.82   | -5.201                |
| 17             | 2   | 3     | 2    | 2.145  | -6.629                |
| 18             | 2   | 3     | 3    | 2.655  | -8.481                |
| 19             | 3   | 1     | 1    | 2.41   | -7.640                |
| 20             | 3   | 1     | 2    | 2.445  | -7.766                |
| 21             | 3   | 1     | 3    | 3.09   | -9.799                |
| 22             | 3   | 2     | 1    | 2.105  | -6.465                |
| 23             | 3   | 2     | 2    | 2.605  | -8.316                |
| 24             | 3   | 2     | 3    | 3.165  | -10.007               |
| 25             | 3   | 3     | 1    | 1.695  | -4.583                |
| 26             | 3   | 3     | 2    | 2.74   | -8.755                |
| 27             | 3   | 3     | 3    | 3.335  | -10.462               |
| Avg.           |     |       |      | 1.967  | -134.74               |

### Table 5. Average S/N ratio response

| level | doc | speed | feed |
|-------|-----|-------|------|
| 1     | 0.0778 | -5.761 | -3.728 |
| 2     | -6.850  | -5.278 | -4.726 |
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| 3        | -8.199 | -3.932 | -6.516 |
| Delta    | 8.277  | 1.829  | 2.788  |
| Rank     | 1      | 3      | 2      |

The total mean S/N ratio = -4.99

![Main Effects Plot for SN ratios](image)

**Figure 4. Response Graph**

It was observed from table 5 and figure 4, that the S/N ratios for depth of cut and feed decreases with increase in their levels where as for speed value of S/N ratios increases with increase in its levels. Values of delta for all parameters is also shown in table 5 which depict that doc has maximum value of delta i.e., 8.277 and hence ranked first, feed and speed are ranked second and third with reduced values as 2.788 and 1.829 respectively and it was also observed that S/N are maximum at level1 for doc, level 3 for speed and level1 for feed so optimum arrangement of parameters is A\(_1\)B\(_3\)C\(_1\).

3.2 Analysis of variance

Evaluation of S / N ratios was completed by ANOVA at a confidence level of 95 percent see table 6. Contribution in percentage of each cutting parameter to the surface roughness is also evaluated by ANOVA. The depth of cut indicates a greater contribution of 76.27% from the table of ANOVA. The error was noticed here at 12.54%.

| Source | Dof | Sum of square | Mean square | F-Value | Contribution |
|--------|-----|---------------|-------------|---------|--------------|
| doc    | 2   | 355.00        | 177.502     | 60.84   | 76.27%       |
| speed  | 2   | 16.18         | 8.088       | 2.77    | 3.48%        |
| feed   | 2   | 35.93         | 17.965      | 6.16    | 7.72%        |
| Error  | 20  | 58.35         | 2.918       |         | 12.54%       |
| Total  | 26  | 465.46        |             |         | 100.00%      |
Table 6 shows that the speed given has little impact on the surface roughness for the given sample, since the speed F value is less than 4. ANOVA's results also show that the depth of cut (76.27%) is the most important turning parameters likewise feed rate (7.72%) and speed (3.48%) (see figure 5).

![Figure 5. Percentage contribution](image)

### 3.3 Confirmation Experiments

When the optimal level of process parameters has been established, the next step is to use this optimal level to check the performance characteristic improvement. The outcomes of the confirmation experiment are shown in Table 7 using optimal turning process parameters.

| Table 7. Optimum parametric conditions | Prediction | Experiment | % change |
|----------------------------------------|------------|------------|----------|
| A<sub>1</sub>B<sub>3</sub>C<sub>1</sub> | A<sub>1</sub>B<sub>3</sub>C<sub>1</sub> |            |          |
| Surface roughness                      | 0.428      | 0.645      | 50.70 %  |
| S/N Ratio (db)                         | 7.38       | 3.80       | 48.50 %  |

From table 7 it was observed that signal to noise ratio changed from 7.38 to 3.80 (a decrement of 48.50%) on account of raise in value of roughness from 0.428 to 0.645 μm (an increment of 50.70%) which represents that the optimal combination (A<sub>1</sub>B<sub>3</sub>C<sub>1</sub>) are good enough for reducing the machined surface roughness.

### 4. Conclusions

The optimization of turning operations is done by taguchi method in this paper. As described earlier, taguchi technology design gives an efficient, well arranged and easy technology for the optimization. Optimized level of parameters (A<sub>1</sub>B<sub>3</sub>C<sub>1</sub>) in turning shows minimum surface roughness (i.e., depth of cut1.5 mm, speed-120m / min. and feed rate-0.20mm / rev). The determination of the optimum cutting parameters is verified by the confirmation experiment. The percentage contribution of depth of cut is higher (76.27%), followed by feed (7.72%) and speed (3.48%). Therefore, the use of this method can significantly improve surface roughness. So, taguchi is most helpful to optimize process parameters in the industry in order to reduce cost and time.

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