MULTI OBJECTIVE OPTIMIZATION OF CUTTING PARAMETERS IN TURNING OPERATION OF STAINLESS STEEL (SS304) TO REDUCE SURFACE ROUGHNESS AND CUTTING FORCES

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ABSTRACT

Turning is a machining operation in which the cutting tool moves linearly while the work piece rotates to remove material. Turning is one the most important machining operation in industries. The process of turning is influenced by many factors such as the cutting velocity, feed rate, depth of cut, geometry of cutting tool cutting conditions etc. The finished product with desired attributes of size, shape, and surface roughness and cutting forces developed depends on the above input parameters. Forces developed during cutting affect the tool life hence the cost of production. Hence the cutting forces must be reduced in order to increase the tool life. At the same time the surface roughness of the finished work piece is also very important. So we have to use multi response optimisation so that the cutting forces and surface roughness are reduced.

The objective of this project is to evaluate the optimal setting of cutting parameters cutting velocity (N), depth of cut (d), feed (f) to have a minimum cutting force and surface roughness (Ra)

In this project dry turning of stainless steel 304 as a work piece and carbide insert tool (SCMT 09T308-TN5120) is performed. The range of cutting parameters are cutting speed (220, 360, 530 rpm), feed rate (0.1, 0.2, 0.3 mm/rev), depth of cut (0.3, 0.6, 0.9mm).

This study makes use of the use of Taguchi design of experiment and Taguchi method to optimize the multi response in turning operation. For this purpose Taguchi design of experiment was carried out to collect the data for surface roughness and various cutting forces. The results obtained are the optimised values of the input parameters and a confirmation test was also done.

Keywords: Cutting Velocity, Depth of Cut, Design of Experiments, Feed, Surface Roughness, Taguchi Method, Turning Operation
I. INTRODUCTION AND LITERATURE REVIEW

**Turning Parameters**

1. **Back Rake** is to help control the direction of the chip, which naturally curves into the work due to the difference in length from the outer and inner parts of the cut. It also helps counteract the pressure against the tool from the work by pulling the tool into the work.

2. **Side Rake** along with back rake controls the chip flow and partly counteracts the resistance of the work to the movement of the cutter and can be optimized to suit the particular material being cut. Brass for example requires a back and side rake of 0 degrees while aluminum uses a back rake of 35 degrees and a side rake of 15 degrees.[1]

3. **Nose Radius** makes the finish of the cut smoother as it can overlap the previous cut and eliminate the peaks and valleys that a pointed tool produces. Having a radius also strengthens the tip, a sharp point being quite fragile.

4. All the other angles are for clearance in order that no part of the tool besides the actual cutting edge can touch the work. The front clearance angle is usually 8 degrees while the side clearance angle is 10-15 degrees and partly depends on the rate of feed expected.[2]

5. Minimum angles which do the job required are advisable because the tool gets weaker as the edge gets keener due to the lessening support behind the edge and the reduced ability to absorb heat generated by cutting.

6. The Rake angles on the top of the tool need not be precise in order to cut but to cut efficiently there will be an optimum angle for back and side rake.

**FIGURE 1.1- Various Cutting Angles in the Cutting Tool**

**Cutting Speed**

The rate at which the material is removed. It is the tangential velocity component of the angular speed which is spindle speed. If the spindle is rotating at $\omega$ rpm then the cutting speed is the product of rpm and radius of the cutting tool. $V=\omega r$.

**Feed Rate**

The rate at which the tool moves with respect to the workpiece i.e how much distance the cutting tool moves with respect to the workpiece removing the material per revolution.

**Depth of cut**

The volume of the material that is removed per time unit. It is influenced by the feed rate and cutting speed.
Cutting Force
1. It is used to evaluate the power required.
2. From cutting force requirement we can decide what kind of electric motor we must use.
3. Depends on the design of machine tool components and body of the tool.

Influence of Cutting Force on Parameters
1. Deformation of the work piece machined that is the surface of the work piece and its strength.
2. Dimensional accuracy and precision of the machined workpiece.
4. Amount of chip formed. If the cutting force is very large than required it leads to the formation of more amount of chip.[3]

Surface Roughness
1. Surface quality of the machined components is very important as it is going to be used in mechanical links and mechanisms.
2. It describes the geometry of the machined surface as well its texture.
3. Characterized by two parameters namely Average Roughness and Maximum peak to valley height.

Influence of Surface Roughness on Parameters:
1. Wear resistance
2. Fatigue strength
3. Coefficient of friction of the work piece
5. Wear rate
6. Corrosion resistance

These properties are defined with respect to the machined work pieces.

Cutting force
Force generated by the cutting tool is called as cutting force. It can be measured using a dynamometer.

Forces
1. The relative forces in a turning operation are important in the design of machine tools. The machine tool and its components must be able to withstand these forces without causing significant deflections, vibrations, or chatter during the operation. There are three principal forces during a turning process:
   • The cutting or tangential force acts downward on the tool tip allowing deflection of the work piece upward. It supplies the energy required for the cutting operation.
   • The axial or feed force acts in the longitudinal direction. It is also called the feed force because it is in the feed direction of the tool. This force tends to push the tool away from the chuck.
   • The radial or thrust force acts in the radial direction and tends to push the tool away from the work piece.
Surface Roughness
1. It is measured using handysurf which is a stylus based instrument.
2. Depth of cut has significant role to produce lower surface roughness.
3. Feed also has got significant role to produce lower surface roughness.
4. Cutting speed has the least effect on producing lower surface roughness.

Machine vibration and machine chattering will also lead to poor surface finish of the workpiece.[5]

II. BRIEF DESCRIPTION OF APPARATUS USED

2.1. Cutting Tool Specification
Cutting Tool: Tool is carbide insert tool SCMT 09T308 TN5120 (ISO catalog number)

![Carbide Insert](image)

2.2 Work piece Composition:
The work piece used is Stainless steel 304. The properties of stainless

Typical Properties of Stainless Steel 304

Typical properties of Stainless Steel 304 are covered in the following table.

<table>
<thead>
<tr>
<th>Property</th>
<th>Metric</th>
<th>Imperial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>8.0 g/cm³</td>
<td>0.289 lb/in³</td>
</tr>
<tr>
<td>Melting Point</td>
<td>1454°C</td>
<td>2650°F</td>
</tr>
<tr>
<td>Co-Efficient of Expansion</td>
<td>18.2 m/m, °C (20-100 °C)</td>
<td>10.1x10⁶ in/in.°F (70-212 °F)</td>
</tr>
<tr>
<td>Modulus of Rigidity</td>
<td>70.3 kN/mm²</td>
<td>10196 ksi</td>
</tr>
<tr>
<td>Modulus of Elasticity</td>
<td>187.5 kN/mm²</td>
<td>27195 ksi</td>
</tr>
</tbody>
</table>

2.3. Talysurf
Handysurf is a hand held device used for measuring surface roughness values. It is a stylus based instrument. Stylus instruments are based on the principle of running a probe across a surface in order to detect variations in height as a function of distance. The type of transducer used largely affects instrument performance. A piezoelectric crystal is often used as the transducer in the less expensive instruments. Other transducer mechanisms include moving coil transducers, capacitance transducers, and linear variable differential transformers (LVDT). Some error can be introduced in roughness measurements when a stylus instrument is used because of several factors. Some of these factors are the size of the stylus, stylus load, stylus speed, and lateral deflection by asperities.[8]
Surface roughness

Center line average roughness – (Ra)

The most common roughness parameter is the average roughness, \( R_a \). This is also referred to as the arithmetic average or the centreline average (CLA). Its designates as \( Ra \).

The average roughness (\( R_a \)) reports the average distance between the surface and the mean line looking at all of the points along the profile.

2.4. Procedure followed

The given work piece of stainless steel SS304 was fixed to the head stock properly. Rough turning process was carried out to remove the material so that the shaft will be of uniform diameter. Rough turning was done using carbide insert to make the shaft of uniform diameter 28 mm. After rough turning based on the Taguchi design of tables the experiment was carried out. The ranges of the values as mentioned previously were taken.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Depth of cut (mm)</th>
<th>Feed (mm/rev)</th>
<th>Speed (m/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level1</td>
<td>0.3</td>
<td>0.1</td>
<td>19.35</td>
</tr>
<tr>
<td>Level2</td>
<td>0.6</td>
<td>0.2</td>
<td>31.66</td>
</tr>
<tr>
<td>Level3</td>
<td>0.9</td>
<td>0.3</td>
<td>46.62</td>
</tr>
</tbody>
</table>

After fixing the above levels the Taguchi design table was constructed which is shown below:

<table>
<thead>
<tr>
<th>S.NO</th>
<th>DEPTH OF CUT</th>
<th>FEED</th>
<th>SPEED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mm</td>
<td>mm/rev</td>
<td>m/min</td>
</tr>
<tr>
<td>1</td>
<td>0.9</td>
<td>0.3</td>
<td>31.66</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
<td>0.2</td>
<td>19.35</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>0.1</td>
<td>46.62</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.3</td>
<td>19.35</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>0.2</td>
<td>46.62</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
<td>0.1</td>
<td>31.66</td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>0.3</td>
<td>46.62</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
<td>0.2</td>
<td>31.66</td>
</tr>
<tr>
<td>9</td>
<td>0.3</td>
<td>0.1</td>
<td>19.35</td>
</tr>
</tbody>
</table>
In this order the experiment was carried out with 15 mm spacing between each reading. The tool was fixed to the dynamometer which was fixed to the tool post. The experiment was done by varying the above parameters in the given order and the corresponding readings of thrust force, radial force and feed force were taken from the lathe dynamometer. The reading of surface roughness Ra was later taken using Talysurf.

III. GRAY RELATIONAL ANALYSIS:

Grey analysis uses a specific concept of information. It defines situations with no information as black, and those with perfect information as white. However, neither of these idealized situations ever occurs in real world problems. In fact, situations between these extremes are described as being grey, hazy or fuzzy. Therefore, a grey system means that a system in which part of information is known and part of information is unknown. With this definition, information quantity and quality form a continuum from a total lack of information to complete information – from black through grey to white. Since uncertainty always exists, one is always somewhere in the middle, somewhere between the extremes, somewhere in the grey area. [9]

\[ X_{ij} = \frac{y_i - \min_j y_j}{\max_j y_j - \min_j y_j} \quad (1) \]

\[ X_{ij} = \frac{\max_j y_j - y_i}{\max_j y_j - \min_j y_j} \quad (2) \]

Where \( y_i \) is the \( i \)th performance characteristic in the \( j \)th experiment. \( \max_j y_i \) and \( \min_j y_i \) are the maximum and minimum values of \( i \)th performance characteristic for alternate \( j \), respectively.

By normalizing, grey relational co-efficient (GRC) is calculated as

\[ \zeta_{ij} = \frac{\min_{i=1}^n \left| X_{ij}^* - X_i \right| + \zeta \max_{i=1}^n \left| X_{ij}^* - X_j \right|}{\max_{i=1}^n \left| X_{ij}^* - X_j \right| + \zeta \max_{i=1}^n \left| X_{ij}^* - X_j \right|} \quad (3) \]

\( X_{ij}^* \) is the ideal normalized result for the \( j \)th performance characteristic. The ideal normalized value is the maximum of the normalized S/N ratio since large normalized S/N ratio is preferred. \( \zeta \) is the distinguishing or identification co-efficient. Generally it is taken as 0.5. The grey relational grade (GRG) is obtained by averaging the grey relational co-efficient corresponding to each performance measure.

\[ \text{Grey Relational Grade (GRG)} \quad \gamma_i = \frac{1}{n} \sum_{j=1}^n \zeta_{ij} \quad (4) \]

3.2. Taguchi method

Taguchi methods are statistical methods developed to improve the quality of manufactured goods and more recently also applied to engineering, biotechnology, marketing and advertising. The work of Taguchi includes three principal contributions to statistics:

Taguchi philosophy is mostly used in engineering optimization processes. It should be carried in three step approach i.e. system design, parameter design, tolerance design. In system design involves, scientific and engineering principles and know-how are used to create a prototype of the product that will meet functional requirements. In Parameter design we optimize the settings of process parameter values for improving performance characteristics and in tolerance design,
Tolerances are set about the target value of the control parameter identified in the parameter design phase and is done only when the performance variation achieved by the settings recognized in the parameter design stage is not satisfactory. [9-21] Taguchi also defined a performance measure known as the signal to noise ratio (S/N) and aims to maximize it by properly selecting the parameter levels.

\[
S/NT = 10 \log \left( \frac{\bar{y}}{s_y} \right)
\]

Larger is the better (maximize):

\[
S/NI = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{y_i^2} \right)
\]

Smaller is better (minimize):

\[
S/NS = -10 \log \left( \frac{1}{n} \sum_{i=1}^{n} y_i^2 \right)
\]

Where \( \bar{y} \) the average of observed data is, \( s_y^2 \) is the variance of \( y \), \( n \) the no of observations and \( Y \) is the observed data.

Fig 3.2- Formulae for Taguchi method

IV. EXPERIMENTAL OBSERVATION & ANALYSIS

The following data was collected from the experiment.

<table>
<thead>
<tr>
<th>S.N</th>
<th>DEPTH OF CUT</th>
<th>FEED</th>
<th>SPEED</th>
<th>THRUST FORCE</th>
<th>FEED FORCE</th>
<th>RADIAL FORCE</th>
<th>SURFACE ROUGHNESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mm mm/re v</td>
<td>m/min</td>
<td></td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>µm</td>
</tr>
<tr>
<td>1</td>
<td>0.9</td>
<td>0.3</td>
<td>31.66</td>
<td>470.4</td>
<td>558.6</td>
<td>352.8</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>0.9</td>
<td>0.2</td>
<td>19.35</td>
<td>842.8</td>
<td>529.2</td>
<td>254.8</td>
<td>1.5</td>
</tr>
<tr>
<td>3</td>
<td>0.9</td>
<td>0.1</td>
<td>46.62</td>
<td>352.8</td>
<td>401.8</td>
<td>176.4</td>
<td>0.9</td>
</tr>
<tr>
<td>4</td>
<td>0.6</td>
<td>0.3</td>
<td>19.35</td>
<td>392</td>
<td>225.4</td>
<td>176.4</td>
<td>1.2</td>
</tr>
<tr>
<td>5</td>
<td>0.6</td>
<td>0.2</td>
<td>46.62</td>
<td>509.6</td>
<td>274.4</td>
<td>205.8</td>
<td>1.1</td>
</tr>
<tr>
<td>6</td>
<td>0.6</td>
<td>0.1</td>
<td>31.66</td>
<td>313.6</td>
<td>205.8</td>
<td>147</td>
<td>1.4</td>
</tr>
<tr>
<td>7</td>
<td>0.3</td>
<td>0.3</td>
<td>46.62</td>
<td>196</td>
<td>88.2</td>
<td>117.6</td>
<td>1.2</td>
</tr>
<tr>
<td>8</td>
<td>0.3</td>
<td>0.2</td>
<td>31.66</td>
<td>254.8</td>
<td>107.8</td>
<td>156.8</td>
<td>1.4</td>
</tr>
<tr>
<td>9</td>
<td>0.3</td>
<td>0.1</td>
<td>19.35</td>
<td>205.8</td>
<td>78.4</td>
<td>107.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The considered factors for optimisation are thrust force and surface roughness.

We proceed by Grey relation analysis method to get the Gray relation Grade (GRG) which can next be entered in the Taguchi design table in MINITAB 14 software for further calculation for multi optimisation.

The gray relation grade was found out by the formula mentioned in the figure 3.1
Table 4.2- calculation of GRG

<table>
<thead>
<tr>
<th>S.No</th>
<th>ACTUAL VALUES</th>
<th>NORMALISED VALUES</th>
<th>GRC</th>
<th>GRG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F N µm</td>
<td>Ra</td>
<td>F N µm</td>
<td>Ra</td>
</tr>
<tr>
<td>1</td>
<td>470.4</td>
<td>1.3</td>
<td>0.5757</td>
<td>0.3333</td>
</tr>
<tr>
<td>2</td>
<td>842.8</td>
<td>1.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>352.8</td>
<td>0.9</td>
<td>0.7575</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>392</td>
<td>1.2</td>
<td>0.6969</td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>509.6</td>
<td>1.1</td>
<td>0.5151</td>
<td>0.666</td>
</tr>
<tr>
<td>6</td>
<td>313.6</td>
<td>1.4</td>
<td>0.8181</td>
<td>0.166</td>
</tr>
<tr>
<td>7</td>
<td>196</td>
<td>1.2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>8</td>
<td>254.8</td>
<td>1.4</td>
<td>0.9099</td>
<td>0.166</td>
</tr>
<tr>
<td>9</td>
<td>205.8</td>
<td>1.4</td>
<td>0.984</td>
<td>0.166</td>
</tr>
</tbody>
</table>

The above obtained GRG (gray relation grade values) will be put in the Taguchi design table for optimisation. Now the parameters thrust force (N) and Ra (µm) have been normalised and converted to GRG which is a constant. Now using MINITAB 14 software we can do the optimisation of the GRG value with respect to the three input parameters namely depth of cut, feed and speed.[11]

The Taguchi design table with GRG constant is shown below.

![Taguchi design table with GRG](image)

The main effects plot and residual plots are the following images.

![Main effects plot using Taguchi method](image)

Fig 4.1- Main effects plot using Taguchi method
V. CONCLUSIONS

- We can see from the main effect plot from the Taguchi method that the optimised parameters or of the levels D2, F3 and S3 respectively which are 0.6 mm depth of cut, 0.3 mm/rev feed and 46.62 m/min speed.
- We can also say that surface roughness depends on the speed i.e the higher the speed the better is the surface finish.
- We also find that Taguchi method can be employed for best optimisation of the parameters.
- Gray relational analysis also proves to be one of the efficient methods for optimisation
- A confirmatory test was conducted to check the optimised parameters and it showed the value of thrust force 12kg or 117.6 kg which is the least force value of the data obtained and surface roughness was found to be 0.8µm.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

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