

# Optimization of Surface Roughness of Bearing Steel during CNC Hard Turning Process

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**Abstract**— AISI 52100 is mainly used to manufacture bearings. The process for manufacturing bearing includes turning process followed by three different stages of grinding operation. Nowadays grinding operation are replaced by hard turning process and it has been proved that hard turning process are 30% cost effective. The machining parameters (cutting speed, feed rate, depth of cut) are optimized with considerations of surface roughness. Taguchi's concepts of orthogonal arrays, signal to noise (S/N) ratio and ANOVA are used to optimize the surface roughness for high speed CNC turning process.

**Keywords**— CNC hard turning, surface roughness, AISI 52100, Taguchi, ANOVA.

## Introduction

The hard turning process is superior to grinding in terms of flexibility, ability to achieve higher material removal rates, possibility to operate without coolants etc [1]. For the above mentioned reasons hard turning is replacing grinding operations in industrial applications. AISI 52100 steel alloy also known as bearing steel is mainly used for manufacturing bearings and are well known for their hardness and toughness. They are always available in pre-hardened form.

The aim or objective of this work is to optimize the process parameters such as speed, feed and depth of cut and to investigate the effect of these input parameters on surface roughness. Then to achieve the surface roughness within the rejection criteria (1.6 $\mu$ m) when grinding operation is replaced by CNC high speed hard turning operation.

## I. HIGH SPEED CNC HARD TURNING PROCESS

### A. Process Parameters

The main process parameters selected for the work are speed (m/min), feed (mm/rev) and depth of cut (mm). The process parameters and their levels are shown in the Table 1.

### B. Workpiece Material

The workpiece material selected for the work is AISI 52100 bearing steel alloy. It is mainly used to manufacture bearings

especially aerospace and automobile bearings. It is always available in prehardened form hence no heat treatments are required. It is delivered fully quenched and tempered to approximately between 700 to 900 HV.

### C. Tool Material

The tool material selected for this work was tungsten carbide tool insert of 0.80 nose radius. The ISO coding is WNMG 120408.

### D. Experimental Setup

The experimental work was carried out at Center for Research in Design and Manufacturing (CRDM), Karunya institute of technology and sciences under the university of Karunya. The design of experiments was done by making use of Taguchi's method and optimization was done by making use of Fuzzy logic unit. AISI 52100 bearing steel round bar of 25 mm diameter and 50 mm length was selected for this work.

The design of experiments are done using Taguchi's L9 orthogonal array and is shown in Table 2. The experimental design proposed by Taguchi involves using orthogonal arrays to organize the parameters affecting the process and the levels at which they should be varies. Instead of having to test all possible combinations like the factorial design, the Taguchi method tests pairs of combinations. This allows for the collection of the necessary data to determine which factors most affect product quality with a minimum amount of experimentation, thus saving time and resources.

TABLE I  
PROCESS PARAMETERS AND THEIR LEVELS

Process parameters	Level 1	Level 2	Level 3
Speed(m/min)	120	160	200
Feed (mm/rev)	0.10	0.12	0.14
Depth of cut(mm)	0.20	0.35	0.50

TABLE 2  
LAYOUT USING L9 ORTHOGONAL ARRAY

Experiment	Speed (m/min)	Feed (mm/rev)	Depth (mm)
1	120	0.10	0.20
2	120	0.12	0.35
3	120	0.14	0.50
4	160	0.10	0.35
5	160	0.12	0.50
6	160	0.14	0.20
7	200	0.10	0.50
8	200	0.12	0.20
9	200	0.14	0.35

II. OPTIMIZATION OF CNC TURNING PARAMETERS

A. Signal To Noise Ratio

There are mainly three categories of performance characteristics

- Lower the better
- Nominal the better
- Higher the better

For ‘lower the better’ type of machining quality characteristic the S/N ratio will be

$$S/N = -10 \cdot \log[1/n \cdot (y_1^2 + y_2^2 + \dots + y_n^2)]$$

For ‘nominal the better’ type of machining quality characteristic the S/N ratio will be

$$S/N = 10 \cdot \log\left[\frac{\mu^2}{\sigma^2}\right]$$

For ‘higher the better’ type of machining quality characteristic the S/N ratio will be

$$S/N = -10 \cdot \log[1/n \cdot (1/y_1^2 + 1/y_2^2 + \dots + 1/y_n^2)]$$

Here for surface roughness, machining time and tool wear we use lower the better type and for material removal rate we use higher the better type. Here  $y_1, y_2, y_n$  etc. are the measured values and  $n$  is the number of replications or trials performed.

B. Single Character Optimization

When a single-response problem is considered, Taguchi method and analysis of variance (ANOVA) can be employed to obtain the optimal level/factor combination of high speed CNC turning process. In the past a lot of researchers studied the effect of various machining parameters in optimizing the machined surface integrity using Taguchi’s method. The S/N

is used to represent quality characteristic and the largest S/N ratio is demanded. In addition, the contribution of each factor is evaluated using the ANOVA.

In this thesis work, for surface roughness, machining time and tool wear lower the better type characteristic equation was used to calculate the signal to noise ratio and for material removal rate higher the better type characteristic equation.

The following Table 3 shows the experimentally obtained surface roughness value for three replication of each experiment. The surface roughness of the machined part was measured by making use of surface roughness tester. The model of the tester is SJ 210 which is a MITUTOYO make. Since there are three replications for each experiment, three readings corresponding to three work specimens are taken and the average value is recorded. The three values are then used to find the S/N ratio.

TABLE 3  
SURFACE ROUGHNESS AND S/N RATIO OF SR

SL.NO	Average Ra	S/N ratio
1	0.839	1.52
2	1.119	-0.997
3	1.287	-2.193
4	1.059	-.506
5	0.901	0.901
6	0.808	1.851
7	0.490	6.177
8	1.002	-0.025
9	1.308	-2.334

The S/N equation used here is lower the better type. Then each combinations corresponding to speed, feed and depth of cut for three different levels were taken and the one with highest average were chosen as the best level. Taguchi’s method of analysing means of the S/N ratio using conceptual approach is used here. The rank indicates the dominant machining parameter. The best combination of input parameters for the best surface roughness is given in the Table 4.

TABLE 4  
RESPONSE TABLE FOR SURFACE ROUGHNESS

Variables	Average level 1	Average level 2	Average level 3
Speed	-0.556	-0.842	<b>1.272</b>
Feed	<b>0.807</b>	-0.040	-0.892
Depth	1.115	-2.866	<b>1.628</b>

From the table it is evident that the best combination for surface roughness will be speed at level 3, feed at level 1, depth of cut at level 3. Thus the values for speed, feed and depth of cut when surface roughness alone was considered were 200m/min, 0.10mm/rev, 0.20mm. Thus a factor level combination of S<sub>3</sub>, F<sub>1</sub>, D<sub>3</sub> was recommended. The results of ANOVA for the S/N ratios of the surface roughness are also shown in table 5. It can be seen that the contribution of factor F to the surface roughness was the largest (32.3%). Thus, feed was most important factor followed by depth of cut as far as surface roughness is concerned. It is shown in table 5.

TABLE 5  
ANOVA OF S/N RATIO OF SURFACE ROUGHNESS

Variables	DOF	SS	MS	Contribution %
S	2	5.323	2.662	9.84
F	2	17.498	8.749	32.3
D	2	14.450	7.225	26.7
Error	2	16.811	8.405	31.1
Total	8	54.083	7.617	100

### III. CONCLUSIONS

This paper has presented the use of Taguchi method in optimization of the high speed CNC turning with single performance characteristics. Performance characteristics namely surface roughness can be improved. It can be concluded that the optimization methodology developed in this study is useful in improving single performance characteristics in high speed CNC turning.

The factor/level combination for surface roughness were speed at level three, feed at level one and depth of cut at level three. Thus, feed was the most important factor followed by depth of cut as far as surface roughness was considered. This work clearly shows that feed is the major factor with a contribution of 32.3 % and the surface roughness value lies within the rejection criteria of 1.6µm.

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