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# Optimization of Process Parameters for CNC Turning of Hard Steel

Dr. Sandesh P. Tanpure #1
# 1 Lecturer, Mechanical Engineering, Sanjivani K.B.P. Polytechnic, Kopargaon, MS, Email : sptanpureme@sanjivani.org.in

***Abstract***— **The global environmental awareness is increased and environmental regulations become more stringent, the negative effects of cutting fluids on the environment are becoming more apparent. In CNC turning of hard materials such as steels, cast iron and super alloys, involves high cutting forces, leads to more power consumption and decreasing tool life which may increases the machining cost. To make machining process environment friendly with minimizing cost of machining, dry cutting is the best solution.**

**Current research work presents optimization of Process parameters (cutting speed, feed rate and depth of cut) to minimize cutting forces for dry CNC turning of ASI 52100 steel using TiAlN coated tungsten carbide tool. Design of experiments is conducted using well known Taguchi's L27 orthogonal array to collect cutting forces data. Optimization of process parameters for cutting forces is done using Taguchi Method in Minitab software. The significance of process parameters on responses is studied using developed model.**

**The depth of cut is found to have more significance on cutting forces, followed by cutting speed.**

***Keywords:*** **CNC Turning, Design of experiment, Taguchi method.**

## I. INTRODUCTION

At present, in high-productivity manufacturing enterprises, the supply, maintenance and recycling costs of cutting fluids account for 13%-17% of the manufacturing cost of the workpiece, while the tool costs only account for 2%-5%. The industrial sector accounts for about one-half of the world's total energy consumption and the consumption of energy by this sector has almost doubled over the last 60 years [1]. The global environmental awareness is increased and environmental regulations become more stringent, the negative effects of cutting fluids on the environment are becoming more apparent. According to statistics, twenty years ago, the cost of cutting fluid was less than 3% of the cost of the workpiece. In CNC turning of hard materials such as steels, cast iron and super alloys, involves high cutting forces, leads to more power consumption and decreasing tool life which may increases the machining cost. To make machining process environment friendly with minimizing cost, Dry cutting is the best solution. Dry cutting is without any cutting fluid during processing is a green manufacturing process that controls the source of environmental pollution. Dry machining is done with the hard coating for cutting tools shown in Fig. 1.1 These hard coatings are thin films that range from one layer to hundreds of layers and have the thickness that range from few nanometers to few millimeters. A good surface finish and longer tool life were achieved using coated tool [2]. Results showed coated tool gives better surface roughness values rather than uncoated tool [3]. It is also observed that uncoated tool outperformed at lower cutting speeds and PVD coated tool outperformed at high cutting speeds [4].The compounds which make up the coatings used are extremely hard and so they are very abrasion resistant. Typical constituents of coating are Titanium Aluminum Nitride (TiAlN), Titanium Carbide (TiC), Titanium Nitride (TiN), Titanium Carbonitride (TiCN) and alumina ($Al_2O_3$).

Fig. 1 : Dry Turning Process (www.global-sei.com)

## II.METHODOLOGY

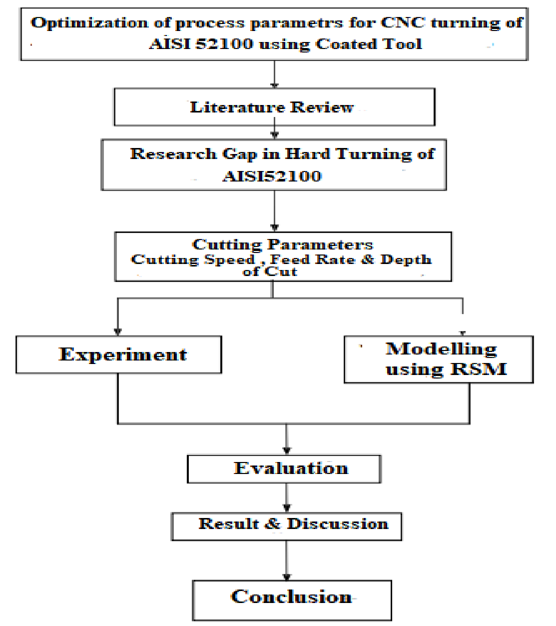



Fig. 2. Flowchart Methodology of FSW Process

In the present research work the methodology adopted is to select the process parameters for response, conduct experiential runs provided by Taguchi's L27 orthogonal array, Optimization process parameters for cutting force using Taguchi Method, study significance of parameters on cutting force using S/N ratios. Research methodology flow chart is shown in Fig.2.

## III EXPERIMENTAL METHOD

### A. *Coating Material*

The coating Material selected is TiAlN with 5 µm thickness and Rockwell hardness of 84 HRC. TiAlN coated carbide tool gives satisfactory tool life for turning hardened steel [13]. The research has been done to compare performance of TiCN and TiAlN coated tools in machining of AISI 4340 hardened steel under dry, wet and minimum fluid application conditions. The performance of the TiAlN tool was observed to be better [14].

### B. *Workpiece Material*

Workpiece material used for experimental work was AISI 52100, as shown in Fig.3. AISI 52100 round bars bearing steel is one kind of special steel with features of high wear resistance and rolling fatigue strength. Experimental trials were conducted on 80 mm length and 40 mm diameter cylindrical steel bar. The total length to be machined during each reading was 40 mm and 30 mm length, that was provided for clamping the work pieces into three jaw chuck. Each piece was used toper form three experiments. A pre-cut of 0.5 mm depth was performed on each work piece prior to actual turning in order to remove the rust or hardened top layer from the surface and to minimize any effect of non-homogeneity on the experimental results.

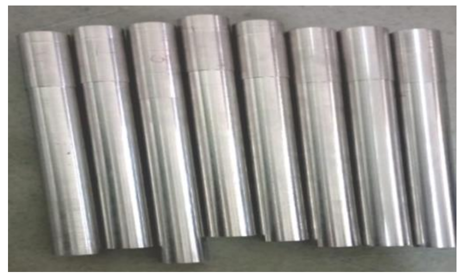


Fig.3 Workpiece material AISI 52100

### C. *Input Cutting parameters and their levels*

The tool manufacturer's catalogue, the lathe's capacity/limiting cutting circumstances, and the values used by researchers in the literature were all taken into consideration when choosing the machining settings. The input parameters for the study includes cutting speed (v), feed rate (f), and depth of cut (d). The performance characteristics chosen to investigate the effect of machining parameters were cutting force (Fc) and Surface roughness (Ra). The three machining parameters and each parameter's three levels are shown in the table 1.

Table 1: Input Cutting parameters and their levels

| Factor | Symbol | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|
| Cutting speed (m/min) | *v* | 100 | 140 | 180 |
| Feed rate (mm/rev) | *f* | 0.1 | 0.15 | 0.2 |
| Depth of cut (mm) | *d* | 0.5 | 1 | 1.5 |

### C. *Design of Experiment*

Design of experiments (DOE) deals with planning, conducting, analysing, and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters. DOE was done by Taguchi method using L27 orthogonal array with 3 level and 3 factors (cutting speed, feed rate and depth of cut) as shown in Table 2.

| No. of Trails | Input Parameters | No. of Trails | Input Parameters |
|---|---|---|---|
| | Cutting Speed (mm/min) | Feed Rate (mm/rev) | Depth of cut (mm) |
| 1 | 100 | 0.1 | 0.5 |
| 2 | 100 | 0.1 | 1 |
| 3 | 100 | 0.1 | 1.5 |
| 4 | 100 | 0.15 | 0.5 |
| 5 | 100 | 0.15 | 1 |
| 6 | 100 | 0.15 | 1.5 |
| 7 | 100 | 0.2 | 0.5 |
| 8 | 100 | 0.2 | 1 |
| 9 | 100 | 0.2 | 1.5 |
| 10 | 140 | 0.1 | 0.5 |
| 11 | 140 | 0.1 | 1 |
| 12 | 140 | 0.1 | 1.5 |
| 13 | 140 | 0.15 | 0.5 |
| 14 | 140 | 0.15 | 1 |
| 15 | 140 | 0.15 | 1.5 |
| 16 | 140 | 0.2 | 0.5 |
| 17 | 140 | 0.2 | 1 |
| 18 | 140 | 0.2 | 1.5 |
| 19 | 180 | 0.1 | 0.5 |
| 20 | 180 | 0.1 | 1 |
| 21 | 180 | 0.1 | 1.5 |
| 22 | 180 | 0.15 | 0.5 |
| 23 | 180 | 0.15 | 1 |
| 24 | 180 | 0.15 | 1.5 |
| 25 | 180 | 0.2 | 0.5 |
| 26 | 180 | 0.2 | 1 |
| 27 | 180 | 0.2 | 1.5 |

Table 2: Number of experimental trials given by L27 orthogonal array with 3 levels and 3 factors

| Experiment | *Fc* (N) |
|---|---|
| 1 | 216.5 |
| 2 | 297.8 |
| 3 | 444.7 |
| 4 | 236.3 |
| 5 | 441.2 |
| 6 | 552.9 |
| 7 | 259.3 |
| 8 | 426.7 |
| 9 | 658.6 |
| 10 | 380.6 |
| 11 | 475.2 |
| 12 | 740.7 |
| 13 | 348.0 |
| 14 | 642.5 |
| 15 | 557.2 |
| 16 | 259.7 |
| 17 | 471.5 |
| 18 | 577.2 |
| 19 | 285.5 |
| 20 | 406.0 |
| 21 | 674.3 |
| 22 | 336.8 |
| 23 | 485.0 |
| 24 | 827.9 |
| 25 | 365.3 |
| 26 | 780.7 |
| 27 | 1004.6 |

Table 3: Experimental results

D. *Cutting force measurement*

In current study, piezoelectric dynamo meter used was used for cutting force measurement in turning process. The piezoelectric dynamo meter was mounted on the lathe's turret by means of an in-house designed fixture plate.

IV RESULTS AND DISCUSSION

*A. ANOVA*

The analysis of variance (ANOVA) is performed to identify the effect of the cutting parameters on the response variables [3,15]. ANOVA was used to investigate which design parameter significantly affected the quality characteristic. ANOVA was performed by separating the total variability of the S/N ratio into contributions from each of the design parameters and the errors. The total variability of the S/N ratio was measured by the sum of the squared deviations from the total mean S/N ratio. P test values can be applied to proceed with the decision-making process [16].

The P value is calculated for each design parameter. Usually, when the P value is < 0.05, the related design parameter appears to have a significant effect on the quality characteristic; when the P value for a factor is > 0.05, that factor is not significant and can be neglected. Percentage contribution is calculated by summing all sum of squares SS and then taking each individual SS and dividing by the total SS and multiplying by 100. The examination of the calculated P test values and percent contribution for all experiment factors also shows a very high influence of factor d on cutting force shown in Table 4.

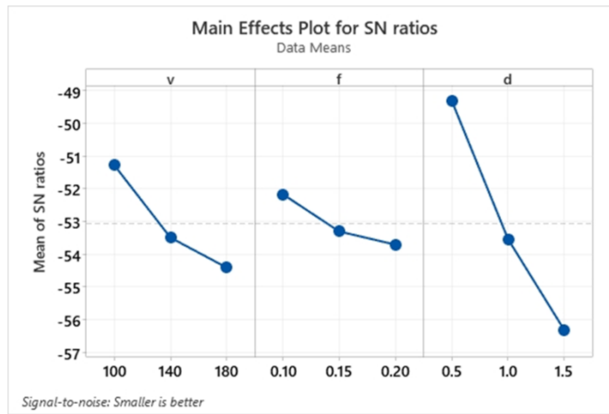
Table 4: Analysis of Variance for SN ratios

| Source | DF | Seq SS | Adj SS | Adj MS | F | P | Contribution (%) |
|---|---|---|---|---|---|---|---|
| v | 2 | 46.10 | 46.10 | 23.049 | 9.48 | 0.001 | 16.56 % |
| f | 2 | 11.43 | 11.43 | 5.713 | 2.35 | 0.121 | 4.11 % |
| d | 2 | 220.85 | 220.85 | 110.425 | 45.42 | 0.000 | 79.33 % |
| **Residual Error** | 20 | 48.63 | 48.63 | 2.431 | | | |
| **Total** | 26 | 327.00 | | | | | 100 |

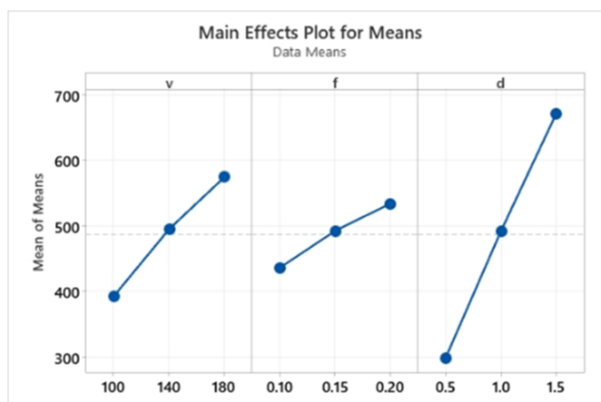
The P value was first examined, and the P values of factors d and v were 0 and 0.001, respectively. Because the P values is < 0.05, factors d and v could be judged to have significant effects on the cutting force. In contrast, the P value of factor f > 0.05 meant that this factor was not significant and could be neglected. Percent Contribution was further examined: The Percent Contribution of the depth of cut (v) and the cutting speed (v) is 79.33 % and 16.59%, respectively. Based on the analysis of experimental factors and ANOVA, it was judged that the depth cut (d) and the cutting force (v) had remarkable effects on the Cutting Force.

*B. Interpretation of Main effects and interaction plots*

Experimental data of cutting force is used to plot main effects plots for SN ratios d means to study the impact of process parameters and to find the significant process parameter. Graphs are plotted in Minitab software.




**(a)**




**(b)**

Graph 1: Main effect plots for cutting force (a) S/N ratio and (b) Mean

The plots for the S/N ratio are shown in graph 4.1. The optimal levels for each experimental factor could be easily determined from these graphs in accordance with Taguchi's 'the smaller the better" performance characteristic. The response graphs showed the variation of the S/N ratio when the setting of the experiment factors was changed from one level to another. Graph 1 suggests that the optimal settings for obtaining the minimum cutting force involve the following combination of the experimental factors: V=100 m/min, f=0.1 mm/rev and d=0.5 mm.

## V CONCLUSION

Present research work presents optimization of process parameters (cutting speed, feed rate and depth of cut) to minimize cutting forces for CNC turning of ASI52100 steel using TiAlN coated tungsten carbide tool. Design of experiments is conducted using well known Taguchi's L27 orthogonal array to collect cutting forces data. Optimization of process parameters for cutting forces is done using Taguchi Method in Minitab 21 software. The significance of process parameters on responses is studied using developed model.

1. Experimentation to study the impact of below parameters on cutting force and surface roughness is successfully completed.

a. Cutting Speed (mm/min)

b. Feed Rate (mm/min)

c. Depth of Cut

2. Experimental setup and plan is developed to select the machine tool, cutting tool, workpiece and cutting tool material, machining parameters and their levels, and performance characteristics (cutting forces and surface roughness). Experiments were designed using full factorial L27 orthogonal array through well-known Taguchi method. Experiments have been conducted for the 27 combinations of orthogonal array to get the cutting forces and surface roughness data.

3. Optimization and prediction of cutting forces

(a) Optimization and Significance of process parameters on cutting forces:

Optimization model have been presented to determine the machining parameters leading to minimum cutting forces during machining. The optimization model has been developed using Taguchi method to find the values of machining parameters leading to minimum cutting forces. Analysis of the influence of each variable (v, f, and d) on the cutting force is performed with S/N response table, ANOVA, main effect plot and interaction plot using the Minitab 21 software package. Higher the value of delta, the more influential the experimental factor. The strongest influence was exerted by the depth of cut (d) and the cutting speed (v), respectively. The P value was first examined, and the P values of factors d and v were 0 and 0.001, respectively. Because the P values is < 0.05, factors d and v could be judged to have significant effects on the cutting force. In contrast, the P value of factor f > 0.05 meant that this factor was not significant and could be neglected. Percent Contribution was further examined: The Percent Contribution of the depth of cut (v) and the cutting speed (v) is 79.33 % and 16.59%, respectively. Based on the analysis of experimental factors and ANOVA, it was judged that the depth cut (d) and the cutting force (v) had remarkable effects on the Cutting Force. The optimal levels for each experimental factor could be easily determined from plots for the S/N ratio in accordance with Taguchi's "the smaller the better" performance characteristic.

The response graphs showed the variation of the S/N ratio when the setting of the experiment factors was changed from one level to another. The optimal settings for obtaining the minimum cutting force involve the following combination of the experimental factors: V=100 m/min, f=0.1 mm/rev and d=0.5mm

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