Optimization of Tool Wear in CNC Turning Operations using Taguchi Method

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Abstract

Determination of tool wear and correspondingly tool life is extremely important in CNC turning operations. Enhancing the quality of the workpiece and reducing the cost to produce it is only possible by the optimization of process parameters, namely, cutting speed, feedrate, and depth of cut. Amount of tool wear can be minimized and the roughness of the surface can be enhanced by the optimization of process parameters. In this study, St 33 and St 52 steel samples were turned for 15 minutes on a CNC lathe using K20 sintered carbide inserts at predetermined process parameters, cutting speed, feedrate, and depth of cut. The data obtained from the experiments was analyzed using Taguchi Method and Pareto ANOVA to obtain optimal process parameters. The values obtained after the analyses were tested on turning three more samples to verify the integrity of the results. By the optimization of CNC process parameters, considerable amount of refinements were obtained for both tool wear and surface quality.

Keywords: Tool wear, Taguchi Method, ANOVA.

1. Introduction

The lathe is one of the oldest and most important machine tools. The turning operation is one of the main operations used in machining of different parts. Mainly single point cutting tools are used in turning operations. There are many different materials of cutting tools suitable for different work materials. Irrespective of tool material and work material (material couple), the cutting tools are subject to extremely severe degradation, mainly wear. Tool wear is mostly affected by process parameters like cutting speed, feedrate, and depth of cut [1].

Optimization of process parameters can be considered as many sub problems, namely, optimization of machining parameters, maximization of process outputs, minimization of operation costs, and minimization of tool wear. These sub problems are often related, and one problem may constrain another, such as the optimization of machining parameters with tool wear as a constraint. Due to the wide variety of manufacturing processes, it is not possible to apply one technique to all operations.

One of the most important and effective factors degrading the standards of manufacturing is tool wear. Machining quality decreases while the tools wear increases. It also raises the total manufacturing costs. In an effective manufacturing system, efficiency and economy should be considered together. When the manufacturing strategies are being designated, it is necessary to define objective functions involving all these parameters together. In CNC turning operations, while process parameters are stated according to the economical tooling use, the total manufacturing costs should also be considered in mind. Most of the studies on the cutting parameters so far are aimed at improving this purpose [2-6].

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This study deals with the optimization of cutting parameters considering the tool wear amount. St 33 and St 52 steel samples were turned for 15 minutes on a CNC lathe using K20 sintered carbide inserts at predetermined process parameters, cutting speed, feedrate, and depth of cut. The data obtained from the experiments was analyzed using Taguchi Method and Pareto ANOVA to obtain optimal process parameters.

2. Materials and Method

2.1 Tools and Workpiece Material

Throughout the experiments, St 33 and St 52 plain carbon steel samples were turned for 15 minutes on a CNC (TC-35 JOHN FORD) lathe (Figure 1) using K20 tungsten carbide inserts. Chemical composition and mechanical properties of steel samples are shown in Table 1. Tool wear amounts from the carbide inserts were measured by a MITUTOYO PROFILE PROJECTOR PJ300 instrument (Figure 2).

Table 1. Chemical composition and mechanical properties of steel samples

Material Standard	C	P	S	Tensile Strength (MPa)	Shear Strength (MPa)	Elongation (%)
St 33	0,18	0,05	0,05	330-500	190	18
St 52	0,22	0,05	0,05	520-600	300	22

Figure 1. The Lathe used for the experiments (TC-35 JOHN FORD)

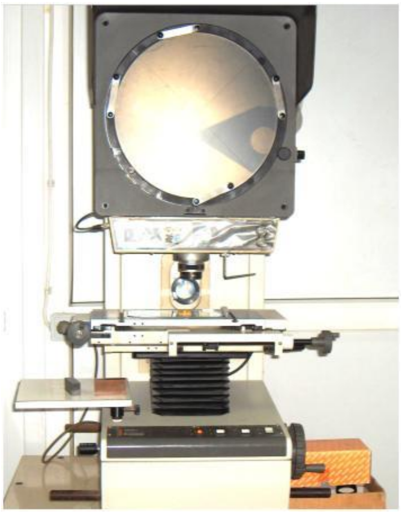

Figure 2. Tool wear testing instrument (MITUTOYO PROFILE PROJECTOR PJ300)

2.2 Taguchi Method (TM)

Taguchi Method (TM) was proposed by Genichi Taguchi, a Japanese quality management consultant. The aim of TM is to minimize the number of experiments to study the entire parameter space. The experimental results are then transformed into a signal-to-noise (S/N) ratio, a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better.

The equation used for calculating S/N ratio for obtaining the smallest wear amount is

$$\text{S/N ratio } (\eta) = -10 \log_{10} \frac{1}{n} \sum_{i=1}^{n} y_i^2 \tag{1}$$

where y_i is observed response value and n is number of replications.

Taguchi suggested a standard procedure for optimizing any process parameters. The steps involved are:

- Determination of the quality characteristic to be optimized.
- Identification of the noise factors and test conditions.
- Identification of the control factors and their alternative levels.
- Designing the matrix experiment and defining the data analysis procedure.
- Conducting the matrix experiment.
- Analyzing the data and determining the optimum levels of control factors.
- Predicting the performance at these levels.

2.3 Analysis of Variance (ANOVA)

ANOVA is a statistical technique for determining the degree of difference or similarity between two or more groups of data. It is based on the comparison of the average value of a common component. In this paper, Pareto ANOVA was used which measures the importance of each process parameter of the process. Pareto ANOVA is a simplified ANOVA method, which is based on Pareto principle [7-8].

The Pareto ANOVA technique does not need *F*-test. It identifies the important parameters and calculates the percentage influence of each parameter on different quality characteristics. The use of both Pareto ANOVA technique and S/N ratio approach makes it less cumbersome to analyze the results and hence, make it fast to arrive at the conclusion.

The sum of squares due to variation about overall mean is

$$SS = \sum_{i=1}^{9}((S/N)_i - (\overline{S/N}))^2 \quad (2)$$

where SS is the sum of squares, S/N is the overall mean of S/N ratio, (S/N)*i* is the S/N ratio for *i*th parameter, and $\overline{S/N}$ is the overall mean of S/N ratio.

For the *i*th process parameter, the sum of squares due to variation about overall mean is

$$SS_i = \sum_{i=1}^{3}((S/N)_{ij} - (\overline{S/N}))^2 \quad (3)$$

where, SS_i is the sum of the square for ith parameter and (S/N)ij is the average S/N ratio of *i*th parameter of *j*th level.

$$\%\ \text{Contribution} = \frac{SSi}{SS} \times 100 \quad (4)$$

2.4 The Experiments

Optimization of process parameters and achieving the high quality at low cost is the ultimate step in TM. Quality can be enhanced by the optimal process parameters obtained by TM. In classical method, enormous numbers of experiments are being necessary when the numbers of process parameters are increasing. These situations are optimized by TM, yielding smaller number of experiments.

The first step of using the technique is to decide the factors and levels of the process, the design of experiment (DOE). Actually, TM is used if the system has more than two factors and levels to be reduced to a reasonable number of experiments. Machining parameters and their levels are given in Table 2.

Table 2. Machining parameters and their levels

Symbol	Machining Parameter	Level 1	Level 2	Level 3
A	Cutting Speed (m/min)	120	150	180
B	Feedrate (mm/rev)	0.1	0.2	0.3
C	Depth of Cut (mm)	0.5	1.0	1.5

In each experiment, St 33 and St52 steel rods with diameters of 35 mm were turned for 15 minutes and after each experiment, wear amount is measured. The experimental plan is outlined in Table 3.

Table 3. Experimental Plan with Orthogonal Layout

Experiment Number	A Cutting Speed	B Feedrate	C Depth of Cut	D Defect
1	1	1	1	-
2	1	2	2	-
3	1	3	3	-
4	2	1	3	-
5	2	2	1	-
6	2	3	2	-
7	3	1	2	-
8	3	2	3	-
9	3	3	1	-

3. Results and Discussion

The experimental results of tool wear for each sample are shown in Table 4. Tool wear values were measured by the testing instrument (MITUTOYO PROFILE PROJECTOR PJ300); and the experimental results were transformed into S/N ratio using Equation (1).

Table 4. The experimental results of tool wear and yielding S/N values

Experiment Number	A Cutting Speed	B Feedrate	C Depth of Cut	Tool wear St33	S/N	Tool wear St52	S/N
1	120	0.1	0.5	0.106	-19.89	1.515	-3.60
2	120	0.2	1.0	0.124	-18.13	1.438	-3.15
3	120	0.3	1.5	0.148	-16.59	4.116	-12.28
4	150	0.1	1.5	0.120	-18.41	0.947	0.47
5	150	0.2	0.5	0.240	-12.39	2.268	-7.11
6	150	0.3	1.0	0.268	-11.43	3.776	-11.51
7	180	0.1	1.0	0.320	-9.89	0.829	1.63
8	180	0.2	1.5	0.367	-8.70	1.135	-1.09
9	180	0.3	0.5	0.421	-7.78	3.374	-10.56

Figure 3 shows the influence of process parameters on tool wear for turning of St 33 steel. The optimum process parameters on tool wear are obtained at Level 1 (120 m/min) for cutting speed, Level 1 (0.1 mm) for feedrate, and Level 3 (1.5 mm) for depth of cut, i.e "A1B1C3". These values were tested on three more samples and the results were proved.

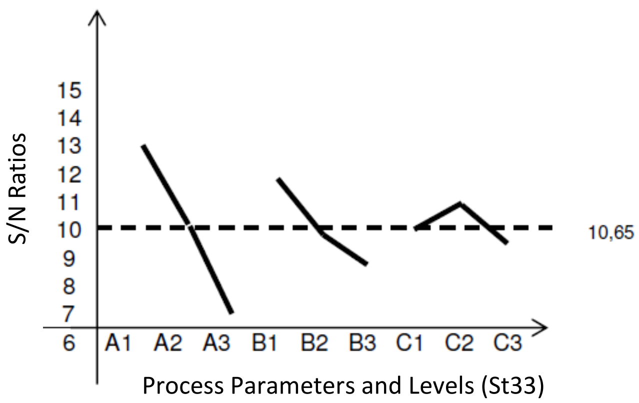

Figure 3. Main effects plot for S/N ratio (tool wear) for St33.

The degree of importance of each parameter is considered, namely, cutting speed, feedrate, and depth of cut for each response is given in Table 5. The calculations were performed by Equations (2), (3), and (4). The table shows that the most important parameter affecting tool wear is cutting speed.

Table 5. Degree of importance of process parameters to tool wear (St33)

Process parameter	Sum of squares	Mean of squares	% Contribution
Cutting Speed	132.66	66.33	78.91
Feedrate	25.59	12.79	15.22
Depth of cut	3.54	1.77	2.12

In Figure 4, the influences of process parameters on tool wear for turning of St 52 steel were given. The optimum process parameters on tool wear are obtained at Level 1 (120 m/min) for cutting speed, Level 1 (0.1 mm) for feedrate, and Level 2 (1.5 mm) for depth of cut, i.e "A1B1C2". These values were also tested on three more samples and the results were proved for St52 again.

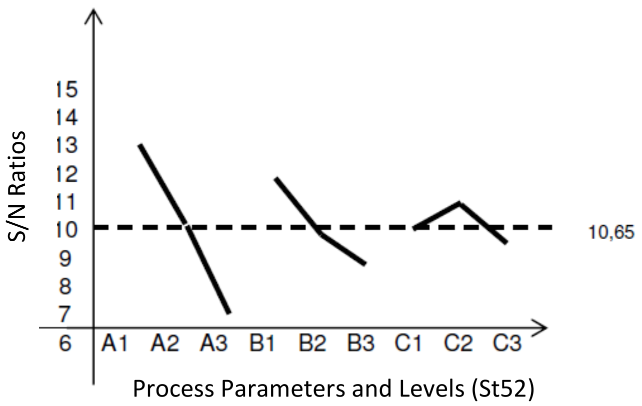

Figure 4. Main effects plot for S/N ratio (tool wear)for St52.

The degree of importance of each parameter is considered, namely, cutting speed, feedrate, and depth of cut for each response is given in Table 6. The calculations were performed by Equations (2), (3), and (4). From the table, it is found that cutting speed is the most important parameter affecting tool wear.

Table 6. Degree of importance of process parameters to tool wear (St52)

Process parameter	Sum of squares	Mean of squares	% Contribution
Cutting Speed	54.60	27.30	74.00
Feedrate	13.59	6.79	18.42
Depth of cut	2.42	1.21	3.28

4. Conclusions

This paper presents the optimization of cutting process parameters namely, cutting speed, feedrate, and depth of cut in turning of St 33 and St 52 steel materials with K20 carbide cutting too. Using the application of Taguchi Method and Pareto ANOVA analysis, the conclusions drawn from this work are as follows:

1. Cutting speed at120 m/min, feed rate at 0.1 mm/rev, and depth of cut at 1.5 mm are found to be optimum for turning of St 33 steel material; cutting speed at120 m/min, feed rate at 0.1 mm/rev, and depth of cut at 1.0 mm are found to be optimum for turning of St 52 steel material.

2. These values are proved by Taguchi Method, ANOVA, and practical testing to be ideal for surface quality of the finished parts.

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