

Effects of machining parameters on tool life and its optimization in turning mild steel with brazed carbide cutting tool

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Abstract. One of the most significant factors in metal cutting is tool life. In this research work, the effects of machining parameters on tool under wet machining environment were studied. Tool life characteristics of brazed carbide cutting tool machined against mild steel and optimization of machining parameters based on Taguchi design of experiments were examined. The experiments were conducted using three factors, spindle speed, feed rate and depth of cut each having three levels. Nine experiments were performed on a high speed semi-automatic precision central lathe. ANOVA was used to determine the level of importance of the machining parameters on tool life. The optimum machining parameter combination was obtained by the analysis of S/N ratio. A mathematical model based on multiple regression analysis was developed to predict the tool life. Taguchi's orthogonal array analysis revealed the optimal combination of parameters at lower levels of spindle speed, feed rate and depth of cut which are 550 rpm, 0.2 mm/rev and 0.5mm respectively. The Main Effects plot reiterated the same. The variation of tool life with different process parameters has been plotted. Feed rate has the most significant effect on tool life followed by spindle speed and depth of cut.

1. Introduction

During the course of history people have changed the manufacturing process dramatically. Instead of items being produced by hand, the owners of the facilities created ways to have machines to produce the items. This change in production, which saw its peak during the Industrial Revolution, gave rise to metal cutting process which over the years has advanced a long way. Metal cutting process is widely used in engineering industries. For a machining process such as turning, cutting conditions like cutting speed, feed, depth of cut plays salient role in the efficient use of a machine tool and thus improving its tool life.

Optimization of the process and accurate estimation of tool life has become indispensable in this age of automation. The goal is to find combinations of these parameters that achieve saving in power consumption, increase in tool life, correct lubrication method and improved surface quality. The results presented in this work should create the window of optimization. It has been established experimentally that there is a definite relationship between spindle speeds, feed rate, depth of cut and tool life. Most



published works on metal cutting has regarded these three parameters as having the greatest influence on tool wear and tool life.

A significant improvement in process efficiency may be accomplished by optimization of process parameter that identifies and determines the areas of critical process control factors leading to desired outputs or responses within acceptable variations which ensures a lower cost of manufacturing. This research work deals with the optimization of these process parameters in order to improve tool life.

2. Design of Experiments using Taguchi Method

Genichi Taguchi, Japanese engineer and statistician invented the Taguchi techniques, which is a methodology that utilizes process control and control charts with product and process design to achieve a robust parameter design. The experiments were conducted by following factorial design of experiments. Design of experiment is an effective approach to optimize the parameters in various manufacturing related process, and one of the best intelligent tool for optimization and analyzing the effect of process variables. The selection of such points in design space is commonly called design of experiments (DOE).

To consider the variation of results, Taguchi method uses the S/N ratio to identify the quality characteristics applied in engineering design problems. In this case, signal is denoted as mean and noise as standard deviation. Thus, optimality is reached by Taguchi method by the maximization of S/N ratio so that the effect of noise is minimized. For the present case of maximization of tool life, higher the better, HB characteristic needs to be used. Again, to know which of the process parameters have a significant influence on the tool life; analysis of variance (ANOVA) as discussed by Montgomery [9] is also applied. A mathematical model based on multiple regression analysis was developed to predict the tool life by relating it with process parameters.

3. Experimental Details

3.1. Experimental Setup

The experimental investigation is carried out on a high speed precision lathe (Make-Hindusthan Machine Tools Limited) under wet condition with soluble oil. The work piece used for turning operation is mild steel. Samples used are round bars of 32 mm diameter and 600 mm length. The cutting tool used for experiment is brazed carbide tool of Sandvik Coromant make. It has rectangle shank-metric 20x20 with tool cutting edge angle of 90° and 0.8mm corner radius.

3.2. Choice of Process Parameters

The working ranges of the parameters for subsequent design of experiment have been selected in accordance with the normal working ranges for such operation. In the present experimental study only spindle speed, feed rate and depth of cut have been considered as process variables since these are the most important process parameters affecting the tool wear and hence tool life. The process parameters and their limits are listed in Table 1.

3.3. Response Variable

In this research work, the main aim is to analyse the effect of machining parameters on tool life and its optimization in turning mild steel. Hence, in this case the response variable used to accomplish this study is the tool life. The tool life was calculated as-

$$\text{RPM} \times \text{mmPR} = \text{mmPM} \text{ and } T = L \times 60/\text{mmPM}$$

Where, RPM = Revolution per minute, mmPR = Millimeter per revolution, L = Effective length of cut, T = Tool life in second

Table1. Design factors and parameters.

Design factors	Unit	Levels		
		1	2	3
Spindle speed (V)	RPM	550	930	1210
Feed rate (F)	mm/revolution	0.2	0.4	0.72
Depth of cut (D)	mm	0.5	0.7	1

3.4. Design of Experiments

In this experimental work related to turning of a mild steel work piece by brazed carbide cutting tool, the experiments were conducted considering three main process parameters namely spindle speed, feed rate and depth of cut under three different levels, low, medium and high. Thus, accordingly, a three level full factorial design of experiments would give ($3^3 = 27$) number of combinations. However, considering Taguchi's design of experiments, we get 9 combinations for 3 parameters and 3 levels.

4. Statistical Analysis on Results Obtained

4.1. Analysis of Signal to Noise Ratio

The idea of Taguchi method is to maximize the S/N ratio, to minimize the effect of random noise factors, which have an impact on the process performance. In the present work, S/N ratio analysis is done with tool life as the performance index and all the calculations are conducted in Minitab software [10]. As tool life is to be maximized, S/N ratio is calculated using HB (Higher the Better) criterion and is given by:

$$S / N = -10 \log \left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2} \right) \quad (1)$$

Where y is the observed data and n is the number of observations.

The mean of the S/N ratio for each level of the factors of V, F, and D are given in Table 3. The delta value is the difference between the largest and the lowest from among the values in each column. A large difference in the S/N ratio indicates that the factor or design parameter is a significant contributor to the achievement of the performance characteristic. A little difference in the S/N ratio from one factor setting to another, hints at the insignificance of the factor with respect to the performance characteristic. It is found from Table 3 that feed rate (F) possesses the highest delta value, and hence, has the greatest influence over the tool life.

Table2. Taguchi combination of process parameters with S/N Ratios.

Spindle speed (V) RPM	Feed rate (F) mm/revolution	Depth of cut (D) mm.	Tool life (T)	S/N ratio
550	0.2	0.5	693	56.8112
550	0.4	0.7	391	51.8515
550	0.72	1	72	37.1418
930	0.2	0.7	315	49.9530
930	0.4	1	77	37.7771
930	0.72	0.5	58	35.3044
1210	0.2	1	187	45.4457
1210	0.4	0.5	126	42.0384
1210	0.72	0.7	15	23.6083

Table 3. Response table for S/N Ratio.

	Spindle speed	Feed rate	Depth of cut
Level	RPM	mm/revolution	mm.
1	48.60	50.74	44.72
2	41.01	43.89	41.80
3	37.03	32.02	40.12
Delta	11.57	18.72	4.60
Rank	2	1	3

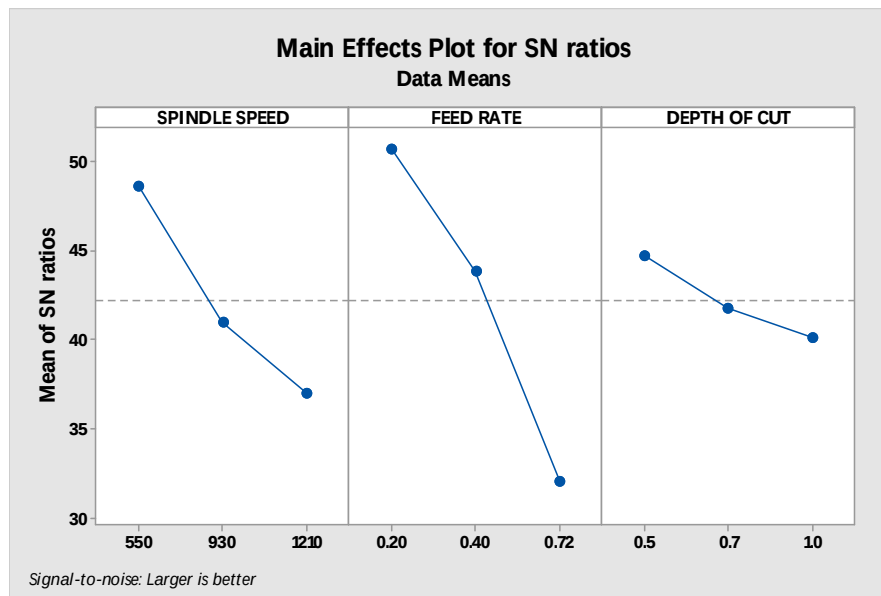


Figure 1. Main effects plot for signal to noise ratio.

The main effects plot (Figure.1) gives the optimal combination of turning process parameters for maximum tool life. Since Taguchi method obtains the optimal level combination by selecting those levels at which S/N ratio is the highest, the optimal combination of parameters is found to be V1F1D1, i.e. lower-levels of spindle speed, feed rate and depth of cut. Moreover, the main effect plot throws some light on the significance of the parameters on the system response. The slope of the main effect plot for each parameter is the determining factor in this case. The plot having higher inclination will have higher influence. From Figure.1, it can be observed that both the factors feed rate and spindle speed are very much significant while factor depth of cut is almost negligible and hence, insignificant.

4.2. Analysis of Variance (ANOVA)

In this study, ANOVA was performed to investigate the statistical significance of the process parameters affecting the tool life. The objective was to analyze the influence of spindle speed, feed rate and depth of cut on the total variance of the results. Table 4 shows the results of the ANOVA with the tool life.

This analysis was undertaken for a level of significance of 0.5%, i.e. for a level of confidence of 99.5%. The ANOVA table also consists of the F-values and the percentage contributions. By comparing the F-values with the tabulated ones, the significance of the factors can be understood. If the obtained F-value of a parameter is greater than the tabulated one, then that particular parameter has a significant influence over the response variable. From Table 4, it can be seen that feed rate has got the most significant influence on tool life at the confidence level of 99.5% within the specific test range. But parameters spindle speed and depth of cut has almost no significance on the tool life.

4.3. Confirmation Test

The experimental confirmation test is the final step for the verification of results based on Taguchi's design approach. The optimal conditions are set at economic levels and a selected number of experiments are performed at specified cutting conditions. Average of the results from the confirmation experiment is compared against the predicted average based on the parameters and levels tested. This

confirmation experiment is highly recommended by Taguchi to verify the experimental results [11]. In this study, a confirmation experiment was conducted by utilizing the levels of the optimal process parameters (V1F1D1) for which the tool life was found to be 688 seconds

Table 4. ANOVA table.

Source	DF	SS	MS	F	Contribution (%)
Spindle speed	2	207.34	103.67	5.50	25.42021700
Feed rate	2	538.19	269.09	14.28 ^a	65.98295837
Depth of cut	2	32.45	16.22	0.86	3.97842211
Error	2	37.68	18.84		4.61962851
Total	8	815.65			100

^aSignificant parameters and interactions

($F_{0.005, 2, 8} = 11.042$)

4.4 Multiple Regression Modeling

A mathematical model has been developed to predict the tool life by relating it with process parameters. The spindle speed, feed rate, depth of cut and interaction among them were considered. The nonlinear 2nd.order regression equation for tool life involving control parameters is obtained through regression analysis. MATLAB software package [12] was used to obtain the generalized mathematical model as follows:

$$T = b_0 + b_1V + b_2F + b_3D + b_{11}V^2 + b_{22}F^2 + b_{33}D^2 + b_{12}VF + b_{23}FD + b_{13}VD \quad (2)$$

Tabulating the value of constants $b_0, b_1, \dots, b_{13}$, we get the following equation:

$$T = 0.4608 + 1.2288*F - 0.8192*D - 1.0240*F^2 - 0.8192*D^2 - 0.0008*V*F - 2.0480*F*D + 0.0004*V*D \quad (3)$$

Arithmetic mean of V, F and D were considered. From equation (3), the following curves have been obtained.

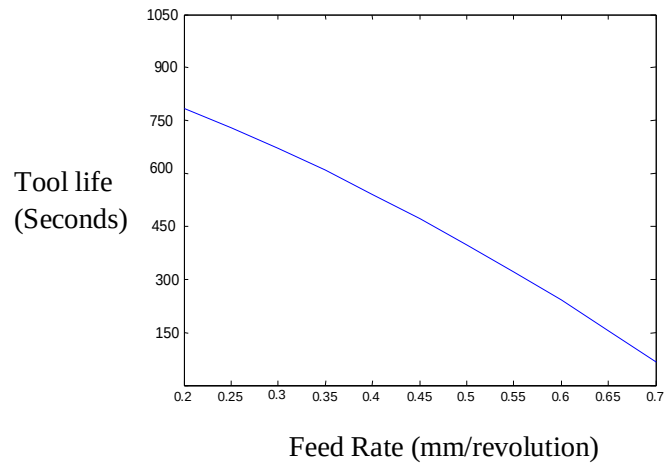


Figure 2. Variation of tool life with feed rate.

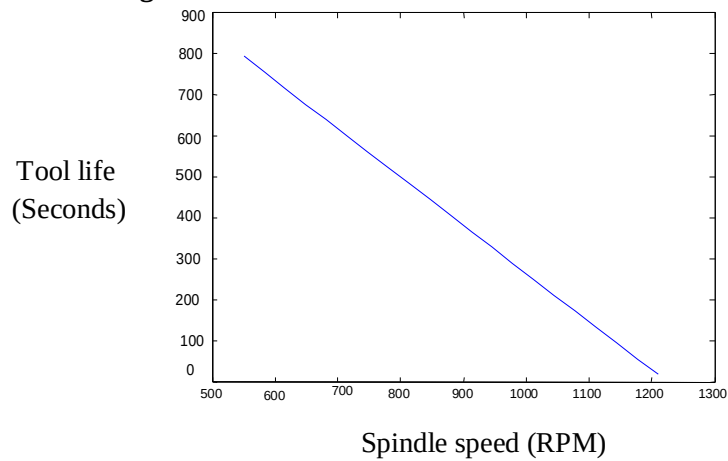


Figure 3. Variation of tool life with spindle speed

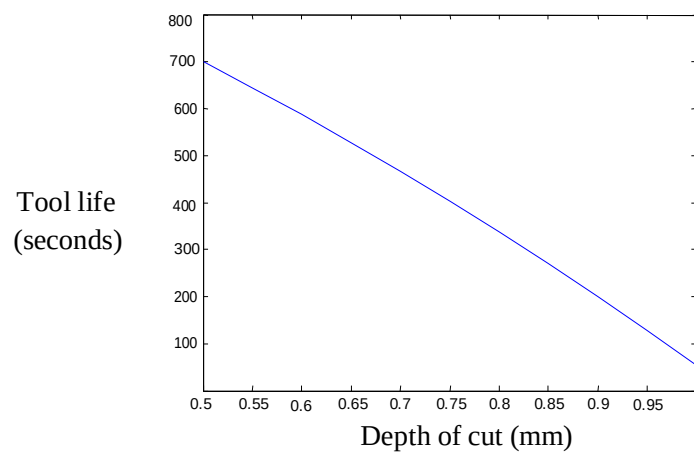


Figure 4. Variation of tool life with depth of cut.

Figures 2, 3 and 4 show the variation of tool life with feed rate, spindle speed and depth of cut respectively. Graphs were plotted between tool life and one parameter, keeping the other two constant at their mean values

5. Conclusion

This study has discussed the importance of the Taguchi method for investigating the effects of process parameters on the tool life in turning of mild steel. From the analysis of the results in the turning process by the signal-to-noise (S/N) ratio approach, analysis of variance (ANOVA), and optimization method of Taguchi, the following can be inferred from the present study:

Statistically designed experiments were performed based on Taguchi's L9 orthogonal array to analyze the tool life as response variable. Data analysis through S/N ratio and ANOVA approaches drew similar conclusions.

Statistical results (at a 99.5% confidence level) show that the spindle speed, feed rate and depth of cut affects the cutting process by 25.42%, 65.98% and 3.97% in the turning of mild steel by brazed carbide cutting tool, respectively.

The maximum tool life is calculated as 688 seconds by Taguchi's optimization method. The analysis of the confirmation experiment for metal removal rate has verified the optimum cutting parameters (V1F1D1), which are spindle speed=550 RPM (V1), feed rate=0.2 mm/rev (F1) and depth of cut =0.5 mm (D1).

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