Estimation of Cutting Tool Wear in Turning using Taguchi Method Depending on Weight of the Removed Tool Metal

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ABSTRACT

This paper focuses on using Taguchi method to determine the optimum turning parameters such as spindle speed, depth of cut, and feed rate, denoted by factor symbols A, B, and C respectively. The effect of cutting parameters on tool wear is depended on the concept of removed weight from the tool metal during machining. The material that has been used as a workpiece is high carbon steel and carbide insert DNMG 443-15 as a cutting tool. Taguchi orthogonal array L_9, quality characteristic "smaller is better", and ANOVA were used to achieve the goal of the research. The results obtained showed that spindle speed is the significant factor of the process followed by the feed rate in terms of their contribution in analysis. The optimum combination of parameters, which was found by applying Taguchi method, is that designated by $A_2B_1C_1$.

Keywords: Taguchi method, Cutting Conditions, Optimization, Tool wear.

تخمين تآكل عدة القطع في عملية الخراطة بتطبيق طريقة تاكوجي اعتماداً على الوزن المفقود من العدة

الخلاصة

تم تطبيق طريقة تاكوجي لإيجاد افضل المتغيرات التي تعطي اقل تآكل للعدة في عملية الخراطة وهي سرعة القطع و عمق القطع و معدل التغذية و قد رمزت A و B و C على التوالي. تم دراسة تأكل العدة عن طريق كمية المعدن المزال من العدة بقياس الفرق بين وزن العدة قبل التشغيل و وزنها بعد التشغيل. تم استخدام مادة الصلب العالي الكاربون كمشغولة، اما عدة القطع فكانت عدة كاربيديه نوع DNMG 443-15. استخدمت مصفوفة تاكوجي العمودية ذات 9 تجارب، حيث اعتمدت خاصية "الأقل هو الأفضل" ، كما طبقت طريقة ANOVA لغرض تحقيق هدف البحث.

بينت النتائج ان سرعة القطع ذات تأثير اكبر من غيرها على تآكل العدة. كما و ان التوليفة المثلى التي تم الحصول عليها من تطبيق طريقة تاكوجي هي ($A_2B_1C_1$).

INTRODUCTION

Metal cutting process considered a complex process. Machining efficiency, quality and economic performance are constraint by the machine tool equipment, the operator skill level, tool and work piece material, cutting parameters, and many other factors [1]. Turning process is one of the most metal cutting processes in which the unwanted material is removed to create rotational parts. The elements of turning process can basically be turning machine or lathe, work piece, and cutting tool as shown in figure (1).

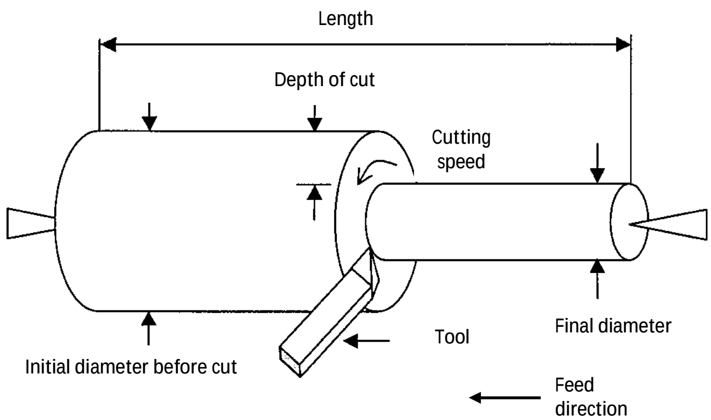

Figure (1) Turning Process.

In turning, the motion of cutting tool is specified by several parameters which are selected depending on the workpiece material, tool material, tool size, and others. Essential cutting parameters that can affect the turning process are spindle speed, feed rate, and depth of cut [2].

There is a lot of researchers used Taguchi method in their studies in different fields related to the present study. S. Ranganathan and T. Senthilvelan [3] studied the influence of the cutting parameters cutting speed, feed rate and depth of cut on tool wear using hot turning at different temperatures of 316 stainless steel, and optimal cutting parameters were obtained by using Taguchi method. In the same direction, Nilrudra Mandal et al [4] used Taguchi method with orthogonal array L9 with parameters depth of cut, feed rate, and cutting speed to find the best optimal cutting condition considering smaller is the better approach. Also, they found that the depth of cut has maximum contribution on tool wear. Krishankant et al [5] applied Taguchi method to optimize the turning process by the effects of machining parameters. Their optimization was on the material removal rate depending on measuring the weight of the workpiece before and after machining. To obtain an optimal tool wear for titanium carbide insert, Hari Singh and Pradeep Kumar [6] optimized the turning process parameters. The effects of selected process parameters on tool wear and subsequent optimal settings of the parameters have been accomplished using Taguchi method.

In the present research determination of the optimum cutting parameters spindle speed, depth of cut, and feed rate affecting the tool wear based on a concept of metal which is removed from the tool (insert) by using Taguchi method has been considered.

TAGUCHI ORTHOGONAL ARRAY (OA)

Taguchi Method is a design optimization methodology that improves the quality of existing products and processes and simultaneously reduces their costs [7]. It provides simple, efficient and systematic approach to optimize designs for performance, quality and cost [8].Taguchi's approach to design of experiments (DOE) is easy to adopt and apply for users with limited knowledge of statistics; hence it is widely used in engineering and scientific [9].

One of the basic elements of Taguchi method is Orthogonal Array (OA). To select an appropriate orthogonal array for the experiments, the total degrees of freedom need to be computed. The degrees of freedom are defined as the number of comparisons between process parameters that need to be made to determine which level is better and specifically how much better it is. For example, a two-level process parameter has one degree of freedom [10]; that is, the degrees of freedom of a parameter are equal to (number of parameter levels -1). There is minimum number of experimental trials required in orthogonal array, so it is more efficient in handling large number of factor variables than traditional factorial design. Additionally, the orthogonal array allows determination of the contribution of each quality influencing factor [11]. In the present research, the standard Taguchi orthogonal array of L_9 (3^4) has been employed. Table (1) shows this array with cutting parameters used here in this research and combination of their levels for each experiment.

Table (1) Taguchi orthogonal array L_9.

No. of experiment	Parameter level combination		
	A	B	C
	Spindle speed (rpm)	Depth of cut (mm)	Feed rate (mm/rev)
No. 1	1	1	1
No. 2	1	2	2
No. 3	1	3	3
No. 4	2	1	2
No. 5	2	2	3
No. 6	2	3	1
No. 7	3	1	3
No. 8	3	2	1
No. 9	3	3	2

SIGNAL-TO-NOISE RATIO S/N

The second basic element of Taguchi method is signal to noise which is the "Quality Characteristic" of performance. There are several (S/N) ratios available depending on response objective of optimization. The characteristic with higher value represents better performance (e.g. tensile strength) is called "larger is better". On the other hand, the characteristic that has lower value represents better performance (e.g machining error) is called "smaller is better" [12, 13]. The present study deals with the minimum metal removed from the tool; therefore, "smaller is better" is used to find the optimum machining parameters that lead to this result and also to estimate the tool life. The signal-noise ratio is calculated from applying the following equations [9].

i. For the "smaller is better" quality characteristic, the equation is:

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

ii. For the "larger is better" quality characteristic, the equation is:

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

Where: S/N is the signal-noise ratio; n the number of observations; and y_i the observed data.

EXPERIMENTAL PROCEDURE

The experiments of turning high carbon steel material are conducted on a traditional machine named Harrison M300. The experiments required are corresponding to orthogonal array mentioned in advance, i.e. that there are nine experiments should be conducted.

CUTTING CONDITIONS AND TOOL

The cutting parameters or factors that are used in this work are: spindle speed, depth of cut, and feed rate respectively. The corresponded levels to them are as shown in Table (2). The carbide insert with specifications DNMG 443-15 is used as a cutting tool. To conduct the nine experiments, nine inserts are used so that each carbide insert is just used one time to achieve one experiment. The weight, in gram, of each tool insert is measured by using a sensitive balance with approximately

± 0.0002 sensitivity. This weight has been called the initial weight, and each carbide tool is weighted for three times to decrease the reading error. After machining the weight of a tool is measured and called the final weight by the same procedures. The differences in weights are measured in milligram. The actual length of the machined part with 55 mm workpiece diameter for each experiment has been fixed that was 180 mm.

Table (2) Factors and their levels used in experiments.

Factors	Unit	Symbol	Conditions levels		
			Level 1	Level 2	Level 3
Spindle speed	rpm	A	800	540	370
Depth of cut	mm	B	0.50	1.00	1.50
Feed rate	mm/rev	C	0.16	0.25	0.40

COMPLETED ORTHOGONAL ARRAY AND RESULTS

After conducting the nine experiments in terms of their combinations, the results are placed in the array shown in Table (3). The orthogonal array is extended, and the results of mean weights of the cutting tool and S/N ratio are placed in the last two columns. The method that is adopted in this study is mainly focused on the weight of the metal removed from the tool through determining the difference between the initial and final weight of the insert tool measured before and after machining. From these weights that are considered as the response of the process parameter the S/N ratio is calculated. Figure (2) shows the numbered carbide inserting (tools) used in conducting the experiments, and figure (3) shows the setup of the machine, including the workpiece and the tool.

Figure (2) Carbide inserting tools.

Figure (3) Machine setup.

Table (3) Experimental results and S/N calculated values.

No. of experiment	Parameter level values A: Spindle speed rpm	B: Depth of cut mm	C: Feed rate mm/rev	Corresponding quantities of levels			Designation	Carbide insert tool weights: Initial weight (g) Average of 3 readings	Final weight (g) Average of 3 readings	Diff. Weight (mg)	S / N ratio value
1	1	1	1	800	0.5	0.16	$A_1B_1C_1$	14.95897	14.95680	2.17	-6.71584
2	1	2	2	800	1.0	0.25	$A_1B_2C_2$	14.97937	14.97660	2.77	-8.83914
3	1	3	3	800	1.5	0.40	$A_1B_3C_3$	14.97967	14.97657	3.10	-9.82723
4	2	1	2	540	0.5	0.25	$A_2B_1C_2$	14.96797	14.96583	2.13	-6.58117
5	2	2	3	540	1.0	0.40	$A_2B_2C_3$	14.97850	14.97547	3.03	-9.63840
6	2	3	1	540	1.5	0.16	$A_2B_3C_1$	14.97763	14.97557	2.07	-6.30541
7	3	1	3	370	0.5	0.40	$A_3B_1C_3$	14.96627	14.96337	2.90	-9.24796
8	3	2	1	370	1.0	0.16	$A_3B_2C_1$	14.96863	14.96573	2.90	-9.24796
9	3	3	2	370	1.5	0.25	$A_3B_3C_2$	14.97170	14.96810	3.60	-11.12605

FINDING THE OPTIMUM LEVELS

After conducting the nine experiments, the results of tool weights and S/N ratios calculated were placed, as mentioned, in the Table (3). Depending on the results, the optimum levels can be estimated using the main effects of both tool weight and S/N ratio. The procedure adopted is by finding the means of values corresponding to each level of the factors. This means, for example, the mean of level 1 for the factor A, spindle speed, is calculated by finding the average for the first three differences weight values in which the level 1 is labeled, but the mean of level 1 for the factor B, depth of cut, is found by taking the average of values corresponding to the places of level 1 in column B of Table (3), that take the places 1, 4, and 7 respectively. For the factor C, feed rate, the mean of level 1 is by places 1, 6, and 8. The other levels are determined in same way but by using the corresponding values for places of levels in array for each factor. Tables (4 and 5) show the calculated means for the tool weights and S/N ratios.

From these tables, the optimum levels can be noticed. Because the quality characteristic "smaller is better" is used, the smallest value is represented the optimum value. Therefore, for spindle speed, level 2 is the optimum value, for depth of cut level 1 is the optimum value, and for feed rate level 3 is the optimum value. These levels that have the designation $A_2B_1C_1$ are marked by "*" symbol. The delta values calculated from the difference between the highest and lowest level value indicate that the spindle speed has more effect than depth of cut and feed rate so that the feed rate takes the second place and depth of cut the third place; therefore, they are ranked as 1, 3, and 2.

Figures (4 and 5) show the plot of the means of the tool weight and the means of S/N ratio. In the Figures, the minimum removed of the tool weight can be noticed at the level 2 of spindle speed, at level 1 of depth of cut, and at level 1 of feed of rate. The minimum quantity of the tool metal removed is considered as an indicator that the tool life will be longer at these levels combinations of cutting conditions.

Table (4) Main effect for carbide insert tool weight.

Factor	Symbol	Average of levels for weight			Delta	Rank
		Level 1	Level 2	Level 3		
Spindle speed (rpm)	A	2.68	*2.41	3.13	0.72	1
Depth of cut (mm)	B	*2.40	2.90	2.92	0.52	3
Feed rate (mm/rev)	C	*2.38	2.60	3.01	0.63	2

* Optimum level

Table (5) Main effect for S/N ratio.

Factor	Symbol	Average of levels for S/N ratio			Delta	Rank
		Level 1	Level 2	Level 3		
Spindle speed (rpm)	A	-8.46074	*-7.50833	-9.87399	2.36570	1
Depth of cut (mm)	B	*-7.51499	-9.24183	-9.08623	1.72680	3
Feed rate (mm/rev)	C	*-7.42307	-8.84879	-9.57120	2.14810	2

* Optimum level

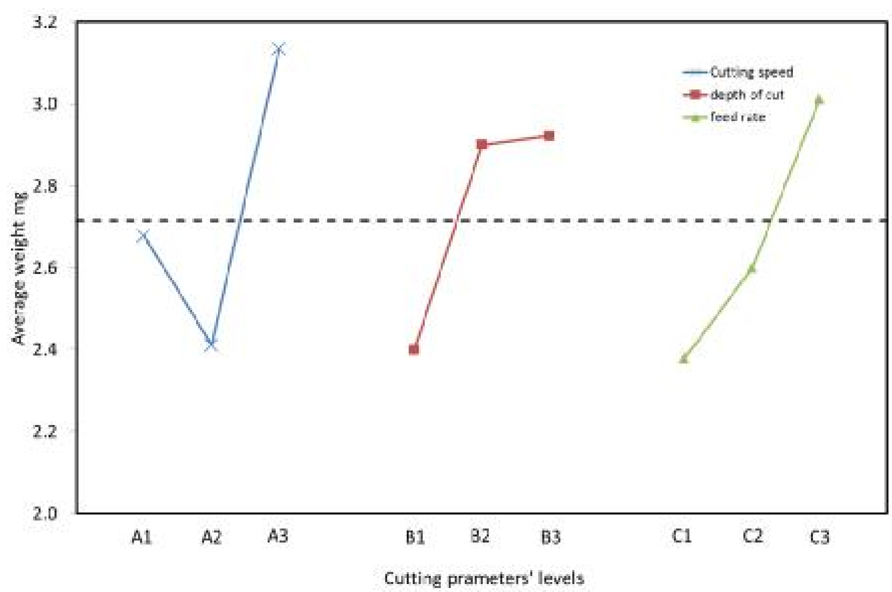

Figure (4) the mean weight plot.

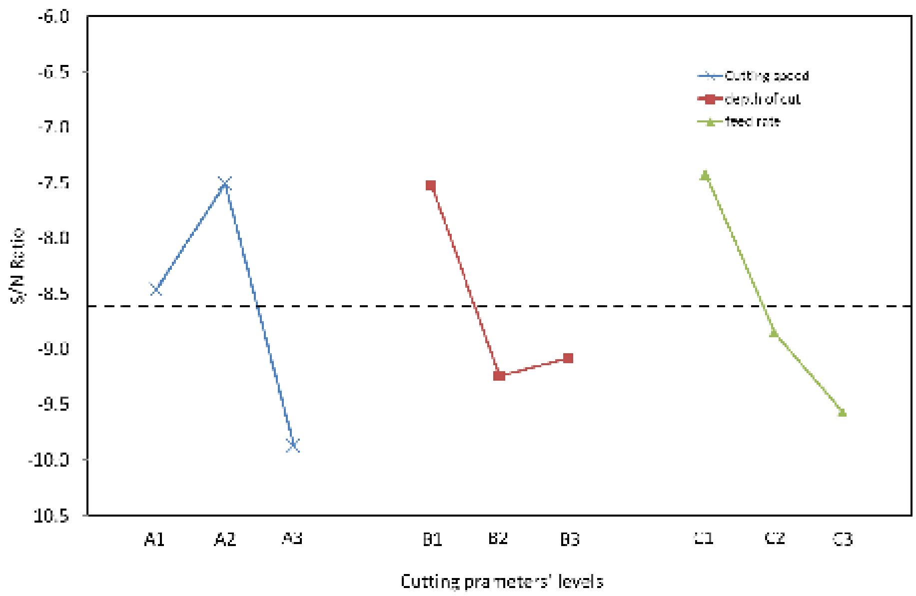

Figure (5) the mean S/N ratio plot.

ANALYSIS OF VARIANCE ANOVA

The ANOVA is used to investigate the statistical significance of the process parameter affecting the response [14]. Therefore, the factor that has more percentage contribution in the process will be identified in analysis. Also, F-test is carried out to judge the significant parameter affecting the response. The larger F-value has more effect on the performance characteristics [14]. ANOVA table, obtained using MATLAB, for the response, tool wear (metal removed), is summarized as shown in Table (6).

Table (6) ANOVA table summary for tool wear (metal removed).

Source	Sum of Squares SS	Degrees of Freedom d.f.	Mean Squares MS	F value (MS/error)	Contribution (%)
Spindle speed	8.5007	2	4.25037	5.29	37.363
Depth of cut	5.4750	2	2.73750	3.41	24.064
Feed rate	7.1690	2	3.58450	4.46	31.510
Error	1.6065	2	0.80325		7.0611
Total	22.7512	8			100

CONFIRMATION TEST

The purpose of confirmation test is that to see how much the predicted results match the experimental values. After the optimum level of the parameters is determined, a confirmation test can be conducted to make a comparison between the results produced by the estimated optimum combinations of levels and the experimental results. For that, three experiments have been replicated at the optimum levels of the process parameter (spindle speed at 540 rpm, depth of cut at 0.5 mm, and feed rate at 0.16 mm/rev). Table (7) shows the results of the test.

Table (7) Confirmation test results.

No. of test	**1**	**2**	**3**
Initial weight (g)	14.95847	14.97870	14.9790
Final weight (g)	14.95653	14.97667	14.97703
Diff. of weight (mg)	1.94	2.03	1.97
Mean of diffs.	1.98 mg		

CONCLUSIONS

In this paper the optimization of parameters design effecting tool wear based on removed weight from carbide insert tool used here has introduced by using Taguchi method. Some conclusions can be summarized depending on the experimental results. The factors used to optimize were: spindle speed, depth of cut, and feed rate.

The main effect analysis indicates that the spindle speed has the main influence on tool wear which was at rank 1. From the main effect analysis results, the best combination levels are level 2 for spindle speed (540 rpm), level 1 for the depth of cut (0.5 mm), and level 1 for the feed rate (0.16 mm/rev). These parameters are ranked as spindle speed, feed rate, and depth of cut. The same results can be indicated from ANOVA results such that the spindle speed has the main influence on the tool wear. The spindle speed has the highest contribution (37.363%) followed by feed rate (31.51%), and finally the depth of cut (24.064%).

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