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International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-6 Issue-3, February 2017

Experimental Investigation for Tool Life by Optimizing Cutting Parameters in Plain Turning Operation by Statistical Methods

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Abstract: ***Rate of production and tool material cost plays a significant role other than the material cost of the part to be made in a production run from economic point of view. The maximum production rate can be achieved if the total time required per piece is reduced to a minimum [1]. The paper presents an optimization technique to achieve minimum tool wear which would lead to reduced tool changing time and tooling cost. The experimental layout is designed based on the Taguchi`s L9 orthogonal array technique and analysis of variance (ANOVA) is performed to identify the effect of the cutting parameters on the response variables. Two different set of response variables are used, first, variation of cutting speed with feed and depth of cut, second, variation of rake angle with feed and depth of cut. The calculation is performed using Minitab-17 software.***

Index Terms: Optimization Technique, Taguchi`s L9 orthogonal array, analysis of variance (ANOVA), Minitab-17

I. INTRODUCTION

In machining process, most of the mechanical energy used to remove material releases in the form of heat. This heat generates high temperature in the cutting region. The higher the cutting speed, the faster the heat generation and higher temperature resulted. The new challenge in machining is to use high cutting speed in order to increase the productivity. This is the main reason for rapid tool wear [1].

The quality of surface obtained depend on machine quality, material type, relative motion between tool and work piece, depth of cut, spindle speed, feed, cutting conditions, etc, and these factors also affect tool wear rate also. Tool variables include, tool material, cutting edge geometry (clearance angle, cutting edge angle, rake angle, nose radius, etc.), and work piece material comprise, material type, mechanical, physical and chemical properties. When rake angle increases, tool life starts improving because the cutting force reduces. Further increase in rake angle results in a larger temperature since the tool becomes thinner and the area available for heat conduction reduces.

The objective is to minimize the flank wear of the cutting tool. When wear reaches a certain value, it increases the cutting force, vibration and cutting temperature, causes surface integrity deteriorated and dimensional error greater than tolerances, then it must be replaced or ground and thus the cutting process is interrupted which include cost of the tool and replacement time which decreases the productivity and increases the cost of production.

The selection of optimum machining parameters for a turning operation is very important task in order to accomplish high performance which means good machinability, better surface finish, less rate of tool wear, higher material removal rate, faster rate of production and low cost. Experimental strategy will be followed to optimize the machining conditions, cutting parameters for the desired quality. Optimization is the science of getting most excellent results subjected to several resource constraints. Statistical design of experiments is used quite extensively in optimization processes. It refers to process of planning the experiments so that appropriate data can be analyzed by statistical methods, resulting in valid and objective conclusions. Practitioners are often more concerned about understanding the priority factors to focus on while designing or controlling a system. They aim to obtain a quick insight of the relative contribution of the priority factors on the performance utilization. Keeping in view these needs, Taguchi method is explored, which provides a mean to study a number of factors at different levels simultaneously and their optimization.

II. TAGUCHI METHOD

Genichi Taguchi, while working at Electrical Communications Laboratory (ECL) of the Nippon Telegraph and Telephone Corporation, Japan has developed a method based on “Orthogonal Array” experiments which give much reduced “variance” for the experiment with “optimum settings “of control parameters. Thus the marriage of Design of Experiments with optimization of control parameters to obtain best results is achieved in the Taguchi Method. "Orthogonal Arrays" (OA) provide a set of well balanced (minimum) experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N), which are log functions of desired output, serve as objective functions for optimization, help in data analysis and prediction of optimum results [2]. Taguchi Method treats optimization problems in two categories;

1. Static Problem:

Generally, a process to be optimized has several control factors which directly decide the target or desired value of the output. The optimization then involves determining the best control factor levels so that the output is at the target value. Such a problem is called as a "Static Problem".

Manuscript published on 28 February 2017.

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Noise is shown to be present in the process but should have no effect on the output! This is the primary aim of the Taguchi experiments - to minimize variations in output even though noise is present in the process. The process is then said to have become robust.

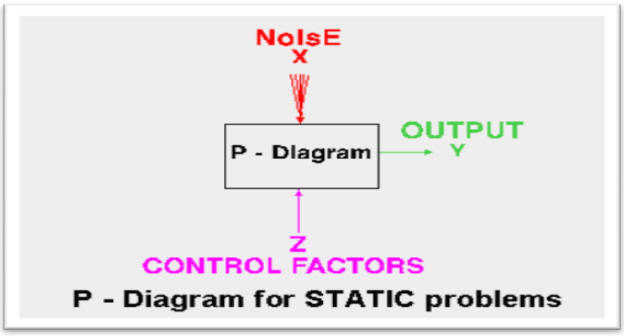

Figure. 1 P - Diagram for Static Problem [2]

2 Dynamic Problems

If the product to be optimized has a signal input that directly decides the output, the optimization involves determining the best control factor levels so that the "input signal / output" ratio is closest to the desired relationship. Such a problem is called as a "Dynamic Problem".

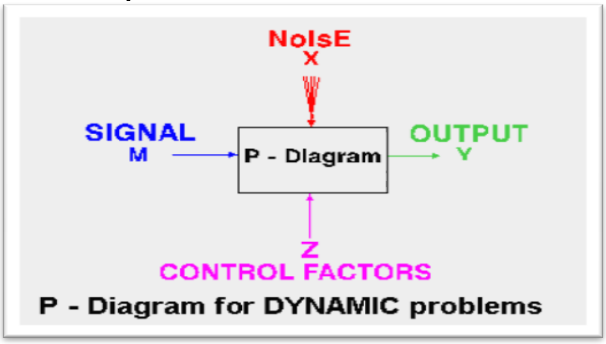

Figure. 2 P - Diagram for Dynamic Problem [2]

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems;

- Smaller the better (STD):- This is chosen for all undesirable characteristics like “defects “etc. for which the ideal value is zero.
- Larger the better (LTB):- This is chosen for characteristics which are desirable whose value should be as large as possible.
- Nominal the better (NTB):- This is chosen when a specified value is most desired.

Applications of Taguchi Methods

- Modern day approach to find the optimal output over a set of given input can be easily carried out by the use of Taguchi method.
- This method has a wide scope of use varying from the agricultural field to medical field and various fields of engineering sciences.
- Agricultural scientist use it to evaluate the production of their crops based on different sets of inputs like the waterfall level, fertility of land, types of seeds used, etc.
- It is also used by the weather department in forecasting of various environmental conditions.

III. ANOVA

Analysis of variance, a best statistical tool for obtaining significance level and involvement of each variable that affects response parameter. It is used to investigate which design parameters significantly affect the quality characteristic. This is to accomplished by separating the total variability of the S/N ratios, which is measured by the sum of the squared deviations from the total mean S/N ratio, into contributions by each of the design parameters and the error.

IV. RESULTS

The experiment was carried out using centre lathe for turning operation using High Speed Tool and Mild Steel work piece..Tool wear was measured using Tool Maker’s Microscope.

1. Effect of Cutting Speed

A. Experimental Results

Results obtained in turning operation for different cutting speed conducted as per levels of orthogonal array under Taguchi’s Method are shown in the Table 1[3].

Table 1 Experimental Results

Cutting speed	Feed	Depth of Cut	Flank Tool Wear Output/ Response
(rpm)	(mm/rev)	(mm)	(mm)
236	0.1295	0.500	0.468
236	0.1397	0.625	0.676
236	0.1448	0.750	0.960
182	0.1295	0.750	0.248
182	0.1397	0.500	0.198
182	0.1448	0.625	0.252
130	0.1295	0.625	0.238
130	0.1397	0.750	0.426
130	0.1448	0.500	0.325

Table 2 Optimum Values of Tool Wear

Level	Cutting speed	Feed	Depth of cut
1	0.3297	0.3180	0.3303
2	0.2327	0.4333	0.3887
3	0.7013	0.5123	0.5447
Delta	0.4687	0.1943	0.2143
Rank	1	3	2

As shown in Table 2, a mean value of tool wear is calculated for each independent factor corresponding to each level and difference is calculated between the highest and lowest value of the mean corresponding to the row that is represented by ‘Delta’.

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Then rank is allotted according to the difference of the value of the mean i.e. first to the highest difference and so on. It can be seen from the table 2 and corresponding rank value for each factor that cutting speed is the highest influencing factor, which has the strongest effect on the tool wear followed by depth of cut and feed.

B. Graphical Analysis

In this analysis various graphs are plotted between mean tool wear for each factor (cutting speed, feed and depth of cut) and the factor itself.

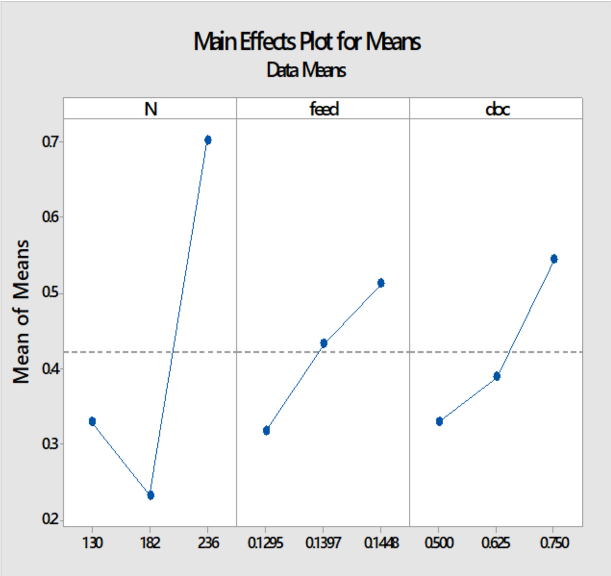

Figure 3 Main Effects Plot for Means

Figure 3 shows the graph between mean value of tool wear and cutting parameters. It can be seen that in the first part as the cutting speed increases from 130 rpm to 182 rpm, mean value of tool wear decreases and in the second part as the cutting speed increases from 182 rpm to 236 rpm, mean value of tool wear increases significantly. This suggests that tool wear has non-linear relationship with cutting speed. Cutting speed cannot be increased or decreased at random. This may lead to increased tool wear. One should identify the range of cutting speed for a given condition which will have minimum tool wear. With increases in feed, mean value of wear increases. The increase in wear value is more when feed increases from 0.1295mm to 0.1397mm than from 0.1397mm to 0.1448mm. This indicate that tool wear increases with increase in feed. And with increase in depth of cut, tool wear is significant for the second part than the first part.

C. Taguchi Analysis

Taguchi analysis, experimental results of tool wear are transformed into signal to noise (S/N) randomized schedule of runs, created at various combinations according to Taguchi design of ratio as shown in following table. Here the signal is representing the desirable value i.e. mean of the output characteristics while the noise represents the undesirable value i.e. squared deviation of output characteristics.

Tool wear were measured via the experimental design for each combination of the control factors by using Taguchi techniques, optimization of the measured control factors were provided by signal-to-noise (S/N) ratios. The lowest values of tool wear are very important for quality improvement of the product and lowering production costs. For this reason, the ‘‘Smaller is better” equation was used for the calculation of the S/N ratio. Main effect plots are generated for S/N Ratio using MiniTab-17 statistical software as shown in tables 3 & 4. While applying Taguchi design analysis to these experimental data, the data for analysis of S/N ratios was generated as shown in Table 3, by which rank value of the factors can be obtained for S/N Ratio.

Table 3 Signal to Noise Ratio (SNR) of Experimental Data

Cutting Speed	Feed	Depth of Cut	Flank Tool Wear	SNR1	Mean1
(rpm)	(mm/rev)	(mm)	(mm)		
236	0.1295	0.500	0.468	6.5951	0.468
236	0.1397	0.625	0.676	3.4011	0.676
236	0.1448	0.750	0.960	0.3546	0.960
182	0.1295	0.750	0.248	12.1110	0.248
182	0.1397	0.500	0.198	14.0667	0.198
182	0.1448	0.625	0.252	11.9720	0.252
130	0.1295	0.625	0.238	12.4685	0.238
130	0.1397	0.750	0.426	7.4118	0.426
130	0.1448	0.500	0.325	9.7623	0.325

Table 4 Response Table for Signal to Noise Ratios

Level	Cutting speed	Feed	Depth of cut
1	9.881	10.392	10.141
2	12.717	8.293	9.281
3	3.450	7.363	6.626
Delta	9.266	3.029	3.516
Rank	1	3	2

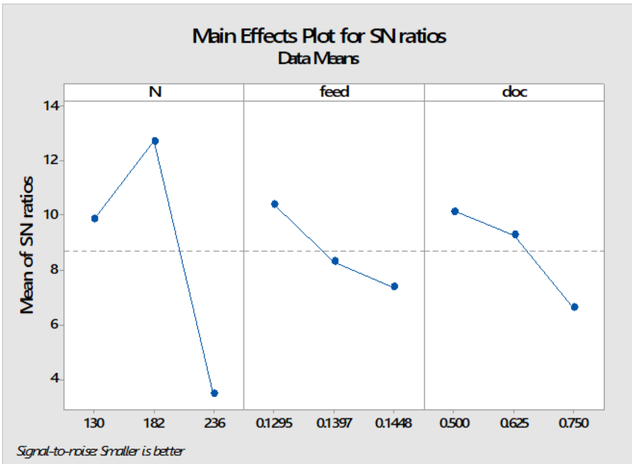

Figure 4 Main Effects Plot for Means (Tool Wear)

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It can be seen from the plot that in order to obtain optimized value of tool wear, cutting speed should be set to 182 rpm, feed to 0.1295mm/rev and depth of cut to 0.500mm because for optimization, largest S/N ratio should be employed.

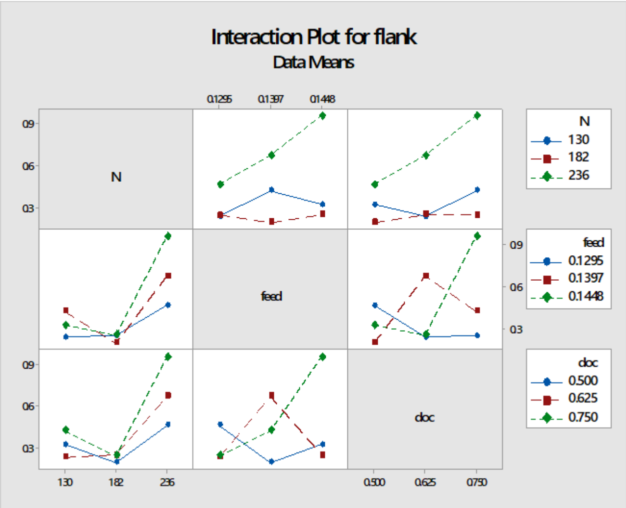

Figure 5 Interaction Plot between various Parameters

D. ANOVA Analysis

Table 5 Analysis of Variance (ANOVA) for Tool Wear

Parameters	Degree of Freedom	Seq SS	Adj SS	Adj ms	F value	P value	Rank	Percentage contribution
Cutting Speed	2	135.259	135.259	67.6293	309.33	0.003	1	72.18
Feed	2	14.440	14.440	7.2201	33.02	0.029	3	11.26
Depth of Cut	2	20.148	20.148	10.0740	46.08	0.021	2	14.48
Error	2	0.437	0.437	0.2186				2.06
Total	8	170.284						100

From Table 5 ANOVA analysis results. For total degree of freedom of 8 and pooled error having degree of freedom as 2, and for 95% confidence level, F value more than 19 are significant. Above table shows that the value of F for all the factors is more than 19, hence results are significant with 95% confidence level. The result shows that cutting speed has highest influence of more than 72% on tool wear followed by depth of cut and feed which is also validated from signal to noise ratio analysis which is shown in earlier table.

2. Effect of Rake Angle

A. Experimental Results

The experimental results obtained in turning operation for different rake angle conducted as per levels of orthogonal array under Taguchi's Method are shown in the Table 6 [4] [5].

Table 6 Experimental Results

Rake Angle	Feed	Depth of Cut	Tool Wear
(Degrees)	(mm/rev)	(mm)	(mm)
4	0.1295	0.500	0.468
4	0.1397	0.625	0.676
4	0.1448	0.750	0.960
8	0.1295	0.750	0.412
8	0.1397	0.500	0.332
8	0.1448	0.625	0.434
12	0.1295	0.625	0.073
12	0.1397	0.750	0.134
12	0.1448	0.500	0.357

Table 7 Optimum Values of Tool Wear

Level	Rake	Feed	Depth of cut
1	0.7013	0.3177	0.3857
2	0.3927	0.3807	0.3943
3	0.1880	0.5837	0.5020
Delta	0.5133	0.2660	0.1163
Rank	1	2	3

It can be seen from the table 7 and corresponding rank value for each factor that rake angle is the highest influencing factor, which has the strongest effect on the tool wear followed by feed and depth of cut.

B. Graphical Analysis

In this analysis various graphs are plotted between mean tool wear for each factor (rake angle, feed and depth of cut) and the factor itself.

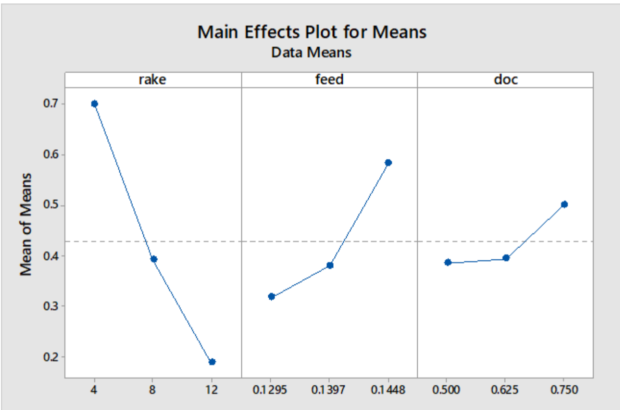

Figure 6 Main Effects Plot for Means

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Figure 6 shows the graph between mean value of tool wear and cutting parameters. It can be seen that as the rake angle increases, mean value of tool wear decreases because cutting force reduces. With increases in feed, mean value of wear increases. The increase in wear value is more when feed increases from 0.1397mm to 0.1448mm than from 0.1295mm to 0.1397mm. Similarly, with increase in depth of cut, tool wear is significant for the second part than the first part.

C. Taguchi Analysis

Table 8 Signal to Noise Ratio (SNR) of Experimental Data

Rake Angle	Feed	Depth of Cut	Tool Wear	SNR1	Mean1
(Degrees)	(mm/rev)	(mm)	(mm)	(db)	
4	0.1295	0.500	0.468	6.5951	0.468
4	0.1397	0.625	0.676	3.4011	0.676
4	0.1448	0.750	0.960	0.3546	0.960
8	0.1295	0.750	0.412	7.7021	0.412
8	0.1397	0.500	0.332	9.5772	0.332
8	0.1448	0.625	0.434	7.2502	0.434
12	0.1295	0.625	0.073	22.7335	0.073
12	0.1397	0.750	0.134	17.4579	0.134
12	0.1448	0.500	0.357	8.9466	0.357

Table 9 Response Table for Signal to Noise Ratios

Level	Rake	Feed	Depth of cut
1	3.450	12.344	8.373
2	8.176	10.145	11.128
3	16.379	5.517	8.505
Delta	12.929	6.826	2.755
Rank	1	2	3

Response Table for Signal to Noise Ratios 'Smaller is better' is shown in Table 9. It is observed from Table 9 that corresponding rank value for each factor that rake angle has the highest influence on the tool wear followed by feed and depth of cut, which is consistent with the mean value that was calculated earlier.

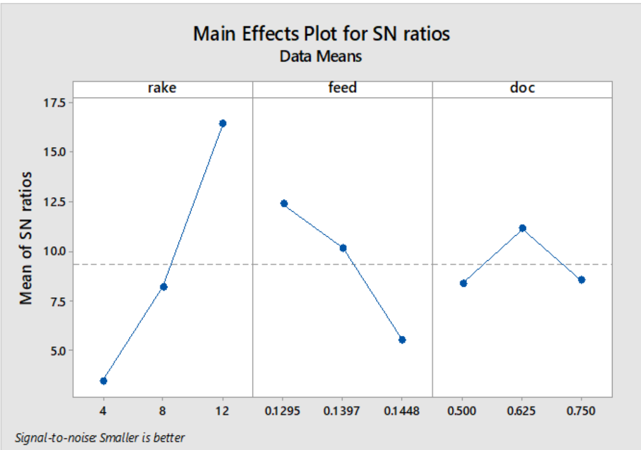

Figure 7 Main Effects Plot for Means (Tool Wear)

It can be seen from the plot that in order to obtain optimized value of tool wear, rake angle should be set to 12 degree, feed to 0.1295mm/rev and depth of cut to 0.625mm because for optimization, largest S/N ratio should be employed.

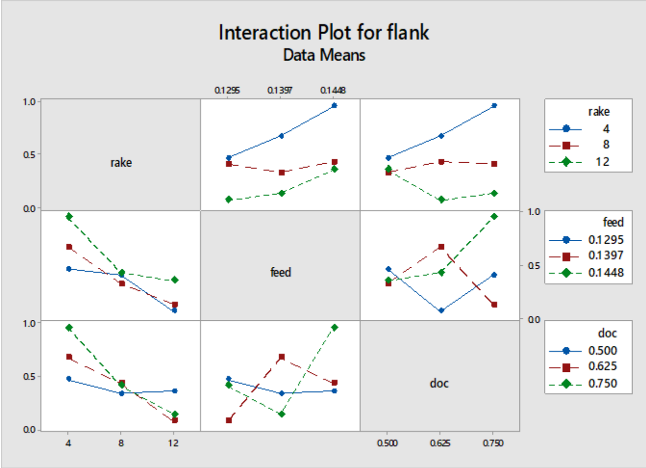

Figure 8 Interaction Plot Between various Parameters

D. ANOVA Analysis

Table 10 Analysis of Variance (ANOVA) for Tool Wear

Parameters	Degree of Freedom	Seq SS	Adj SS	Adj MS	F value	P value	Rank	Percentage contribution
Rake Angle	2	0.40067	0.40067	0.20034	12.79	0.073	1	69.90
Feed	2	0.11593	0.11593	0.05797	3.70	0.213	2	20.22
Depth of Cut	2	0.02520	0.02520	0.01260	0.80	0.554	3	4.39
Error	2	0.03132	0.03132	0.01566				5.46
Total	8	0.57313						100

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From Table 10 ANOVA analysis, total degrees of freedom are 8, which consist of error which accounts for 2 degrees of freedom. Critical value of F at 95% confidence level with (2, 8) degrees of freedom is 4.46. Results shows that rake angle corresponds to F value greater than critical value which has highest influence on tool wear followed by the value for feed which is close to the critical value and depth of cut which has not significant influence on tool wear. Percentage contribution of the cutting parameters on the tool wear is: Rake angle – 69.90%, Feed – 20.22%, Depth of cut – 4.39%

V. CONCLUSIONS

Results obtained from the statistical methods shows that, of the two sets of cutting parameters that are used as input variables, cutting speed has higher influence on the tool wear than the rake angle with respect to the feed and depth of cut.

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