Optimization of Turning Parameters for Surface Finish on Aluminium-2014 based on the Taguchi Method

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***Abstract---* In this study the effect and optimization of turning parameters namely Cutting Speed, feed and Depth of Cut on Surface Finish were investigated using Taguchi Method. The experimentation was conducted under varying conditions of the above parameters. An orthogonal Array, Signal to Noise (S/N) ratio and Analysis of Variance (ANOVA) were employed to study the performance characteristics in the turning of commercial Al-2014 alloy using the inserts TNMG 160408 and TNMG 160412 the conclusions revealed that surface finish increased with an increase in Cutting Speed, decrease in feed rate and increase in depth of cut with feed rate and depth of cut being the most influencing parameters with 28.05% and 28.37% contribution respectively as determined by one-way ANOVA.**

***Keywords---* Surface roughness, Taguchi Method, Turning, Analysis of Variance, Orthogonal Array, Signal to Noise Ratio, Al-2014**

I. INTRODUCTION

A. Background

In modern industry the goal is to manufacture low cost, high quality products in short time. Automated and flexible manufacturing systems are employed for that purpose along with computerized numerical control (CNC) machines that are capable of achieving high accuracy and very low processing time [4]. Turning is the first most common method for cutting and especially for the finishing machined parts. In a turning operation, it is important task to select cutting parameters for achieving high cutting performance. Usually, the desired cutting parameters are determined based on experience [5] or by use of a handbook.

Cutting parameters are reflected on surface roughness, surface texture and dimensional deviations of the product. The alloy which was used for the experimentation is used in the Aircraft Industry [3] for the production of Landing gear struts, which being a critical component require the greatest reliability and so optimal surface roughness is to be maintained [6]. Surface roughness, which is used to determine and to evaluate the quality of a product, is one of the major quality attributes of a turned productand a factor that greatly influences manufacturing cost. It describes the geometry of the machined surfaces and combined with the surface texture. The mechanism behind the formation of surface roughness is very complicated and process dependent. To select the cutting parameters properly, several mathematical models based on statistical regression or neural network techniques have been constructed to establish the relationship between the cutting performance and cutting parameters [1]. Then, an objective function with constraints is formulated to solve the optimal cutting parameters using optimization techniques. Therefore, considerable knowledge and experience are required for this approach. In this study, an alternative approach based on the Taguchi method [2] is used to determine the desired cutting parameters more efficiently [7]there were three purposes of this project. The first was to demonstrate a systematic procedure of using Taguchi parameter design in process control of turning machines. The second was to demonstrate a use of the Taguchiparameter design in order to identify the optimum surface roughness performance with a particular combination of cutting parameters in a turning operation and the last being finding the contribution of each parameter towards surface roughness by ANOVA.

II. TAGUCHI DESIGN OF EXPERIMENTS

A. Introduction, Signal to Noise Ratios and methodology

Taguchi methods are statistical methods, or sometimes called robust design methods, developed by Genichi Taguchi [8] to improve the quality of manufactured goods, and more recently also applied to engineering, biotechnology, marketing and advertising. Professional statisticians have welcomed the goals and improvements brought about by Taguchi methods, particularly by Taguchi's development of designs for studying variation.

The advantage of Taguchi Method lies in its simplicity The traditional experimental designs methods being too complex require large number of experimental runs [2] while Taguchi's standard orthogonal arrays could achieve nearly accurate outputs with considerably shorter runs through simultaneous and independent evaluation of two or more parameters for their ability to affect the variability of a particular product or process characteristic [6]. A loss function is thendefined to calculate the deviation between the experimentalvalue and the desired value. Taguchi recommends the useof the loss function to measure the performance characteristic deviating from the desired value. The value of the lossfunction is further transformed into a signal-to-noise (S/N) ratio [11]. Usually, there are three categories of the performance characteristic in the analysis of theS/Nratio, thatis, the lower-the-better, thehigher-the-better, and the nominal-the-better. TheS/Nratio for each level of processparameters is computed based on theS/Nanalysis.Regardless of the category of the performance characteristic, the largerS/Nratio corresponds to the better performance characteristic. Therefore, the optimal level of theprocess parameters is the level with the highestS/Nratio [9]. In this experiment however the performance characteristic which is under consideration is only the surface roughness, whose value if minimal is always recommended as it directly translates into surface finish. So we use the performance characteristic category of smaller the better for analysis. The equation of which is given by:

$(S/N)_{SB}$= -10 $\log_{10}$ [mean of sum of squares of measured data]

B. Control Factors, Levels and Orthogonal Array

Taguchi Method of Design of Experiments requires certain standardized arrays made by G. Taguchi. The arrays are selected based on the number of control factors and their levels of variability [10]. The control factors selected for the experiment were Cutting Speed (m/min), Feed Rate (mm/revolution), and depth of cut (mm). Each of these factors or parameters was varied on 3 levels. For varying 3 factors on 3 levels a Taguchi L_9 array was selected [8] which had 9 experimental runs.

The levels for cutting parameter ranges and initial parameter values were chosen from the handbook recommended for the tested material. These parameter values were entered into the Taguchi standard L_9 array (Table I) and experimental runs were conducted based on the parameter combinations in the array.

TABLE I
STANDARD L_9 ARRAY FOR TAGUCHI DESIGN OF EXPERIMENTS

Expt	Cutting Speed,v (m/min)	Feed Rate, f (mm/rev)	Depth of Cut, d (mm)
1	60	0.05	0.4
2	60	0.1	0.8
3	60	0.15	1.2
4	90	0.05	0.8
5	90	0.1	1.2
6	90	0.15	0.4
7	120	0.05	1.2
8	120	0.1	0.4
9	120	0.15	0.8

II. EXPERIMENTATION

A. Preparation, Materials and Tools

The experiment was conducted in a SANDS Superturn Lathe with FANUC 0i Mate control. Al-2014 (an alloy of aluminium 2000 series with 3-4% Cu as main alloying element) work pieces were purchased as two 1500 mm rods having 34 mm diameter. It was cut into 25 pieces of 120 mm length and numbered for the runs.

The tool insertsused were TNMG 160408 (KCP25) and TNMG 160412 (K25P) both being carbide grade tools with the former with a TiN-TiCN-Al_2O_3coating and the latter with a more premium grade advanced multilayer TiN-Al_2O_3 coating. TNMG tools were preferred since the holder used was designed for the same. TNMG 160408 used for the first set of experiments and TNMG 160412 for the second set of experiments. The experimentation was conducted with two commonly available tools to identify whether the type of tool used had any significant impact on the surface roughness produced.

B. Measurement of Surface roughness

The results obtained as R_a values were measured using a Talysurf (MitutoyoSurftest SJ210). The work was secured in a V-block and the detector of the talysurf was allowed to carefully traverse the machined surface profile of the workpiece. The results were displayed as R_a values on the LCD Screen on the Talysurf unit. $R_a$is the arithmetic average of the absolute values of the roughness profile ordinates, also known as Arithmetic Average (AA) or Center Line Average (CLA). The average roughness is the area between the roughness profile and its mean line, or the integral of the absolute value of the roughness profile height over the evaluation length. The values were recorded in the experiment table II and table III.

III. TAGUCHI OPTIMIZATION

Taguchi method was implemented for optimizing the experiment and to find the optimal parameters for best surface finish. The software Minitab 16 [12] was used for Taguchi design of experiments and optimization.

Signal to noise ratio Analysis of Taguchi optimization was carried out using Minitab-16 under the parameter ‘lower is better’ since this specifies that lowest value of surface roughness value $R_a$indicates best surface finish. Taguchi analysis includes plotting the graphs of signal to noise with each of the turning parameters. The signal to noise ratio is the ratio of the desired output with the undesirable factors. The signal to noise ratios can then be analyzed using Main effect plots for signal to noise ratios. The result is that a separate graph for each of the parameter is obtained. The highest point on the graph represents the optimal level (best signal/ least noise) of that factor for best surface finish, the lowest being the least optimal(worst signal/ more noise). Thus by analyzing the highest points on each graph, the optimal parameters for best surface finish can be identified.

The optimization was conducted for both sets of tools and the results are tabulated in tables II and III along with surface roughness (R_a) values. The Main effects plots for S/N ratios for the two tools are given in Figures 1 and 2.

TABLE II

EXPERIMENTAL ARRAY AND RESULTS FOR TNMG 160408

Expt	Cutting Speed,v (m/min)	Feed Rate, f (mm/rev)	Depth of Cut, d (mm)	R_a for TNMG 160408	S/N Ratios
1	60	0.05	0.4	0.193	14.2889
2	60	0.1	0.8	0.176	15.0897
3	60	0.15	1.2	0.141	17.0156
4	90	0.05	0.8	0.189	14.4708
5	90	0.1	1.2	0.183	14.7510
6	90	0.15	0.4	0.137	17.9239
7	120	0.05	1.2	0.120	16.5948
8	120	0.1	0.4	0.192	14.3340
9	120	0.15	0.8	0.173	15.2391

TABLE III

EXPERIMENTAL ARRAY AND RESULTS FOR TNMG 160412

Expt	Cutting Speed,v (m/min)	Feed Rate, f (mm/rev)	Depth of Cut, d (mm)	R_a for TNMG 160412	S/N Ratios
1	60	0.05	0.4	0.158	16.0269
2	60	0.1	0.8	0.174	15.1890
3	60	0.15	1.2	0.119	18.4891
4	90	0.05	0.8	0.106	19.4939
5	90	0.1	1.2	0.118	18.5624
6	90	0.15	0.4	0.171	15.3401
7	120	0.05	1.2	0.091	19.0935
8	120	0.1	0.4	0.101	19.9136
9	120	0.15	0.8	0.137	17.2656

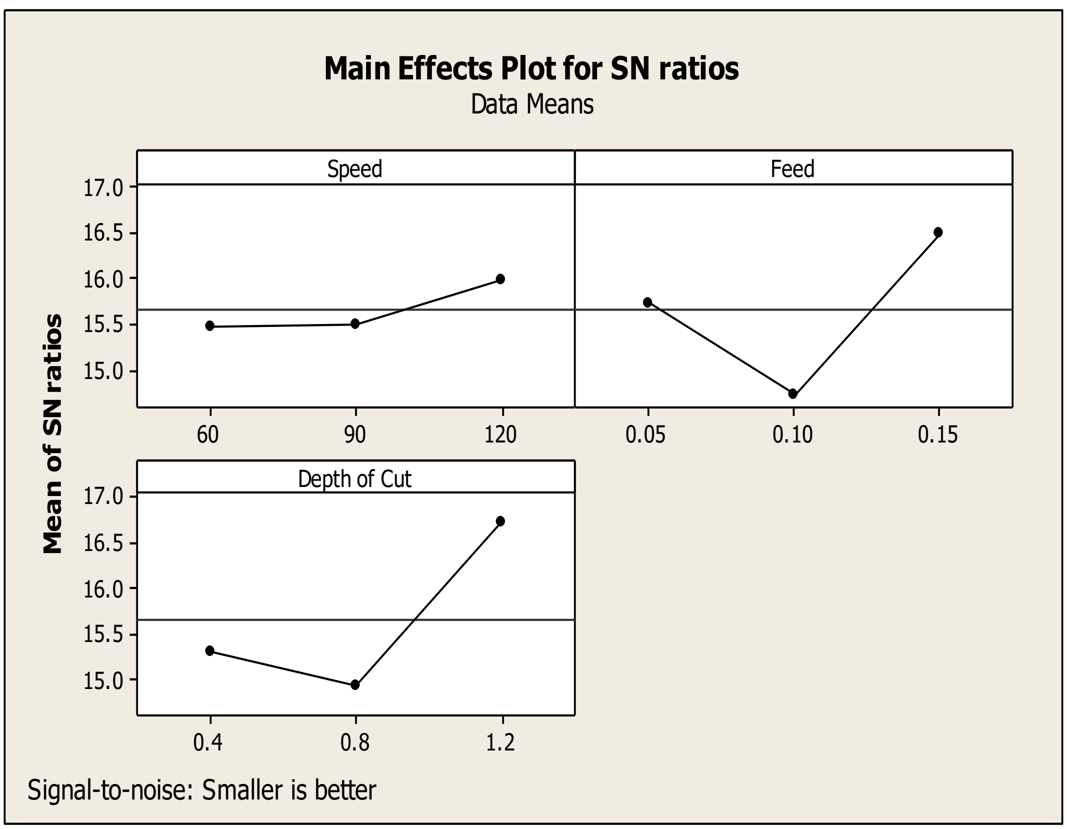

Figure 1 Main effects plot for S/N ratios for the tool TNMG 160408

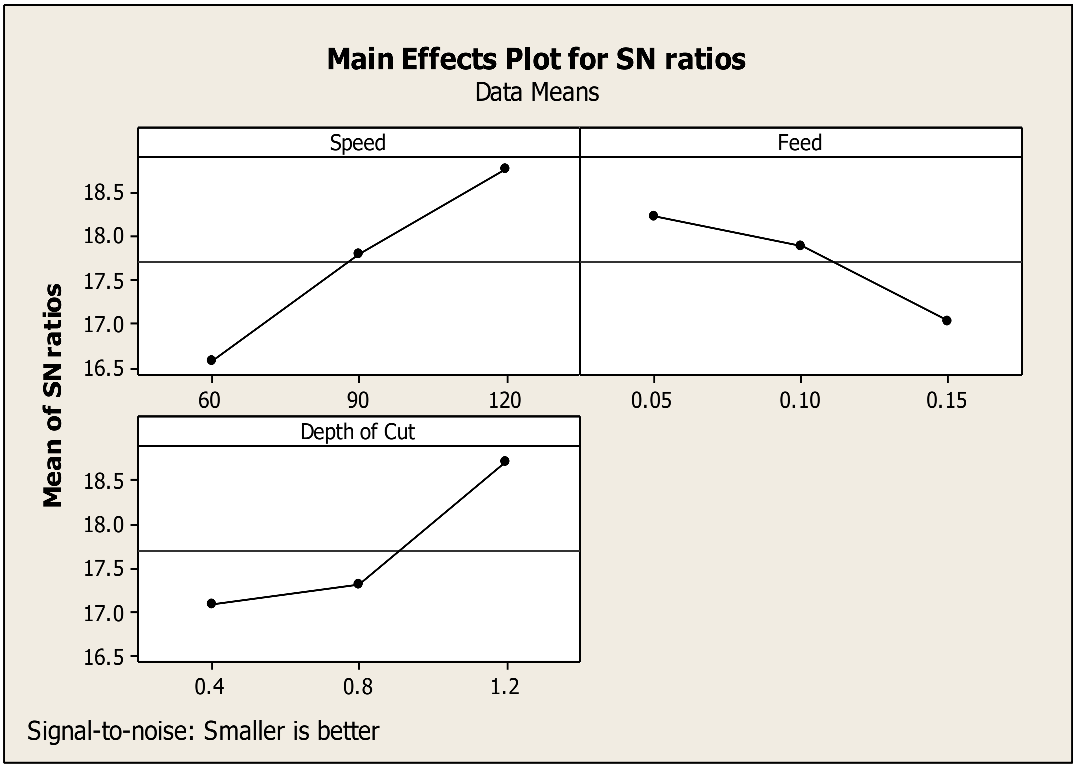

Figure 2 Main effects plot for S/N ratios for the tool TNMG 160412

Analysis of each of the graphs of speed, feed and depth of cut for the tool TNMG 160408 (Figure 1) shows that: Speed level of 3, Feed level of3 and Depth of Cut level of 3 represent the best parameters for optimum surface finish. This is tabulated on Table IV. The corresponding surface roughness R_a valueobtained by turning a separate workpiece on the obtained optimal parameters is given on Table V.

Similar analysis of the main effects plot of speed, feed and depth of cut for the tool TNMG 160412 (Figure 2) shows that a Speed levelof 3, feed level of 1 and depth of cut level of 3represent the best parameters for optimum surface roughness and is tabulated on Table VI. The corresponding surface roughness R_a value obtained by turning a separate workpiece on the obtained optimal parameters is given on Table VII. An improvement in surface finish was also noticeable by the analysis of surface roughness R_a values of TNMG 160412 from table III and an improved surface roughness was also obtained with optimal parameters.

TABLE IV

OPTIMUM LEVEL OF PARAMETERS FOR TNMG 160408

Parameters	Levels	Values
Speed, v (m/min)	3	120
Feed, f (mm/rev)	3	0.15
Depth of Cut, d (mm)	3	1.2

TABLE V

OPTIMUM R_aVALUE (TNMG 160408)

Speed,v (m/min)	Feed, f (mm/rev)	Depth of Cut, d (mm)	R_a (optimized)
120	0.15	1.2	0.118

TABLE VI

OPTIMUM LEVEL OF PARAMETERS FOR TNMG 160412

Parameters	Levels	Values
Speed, v (m/min)	3	120
Feed, f (mm/rev)	1	0.05
Depth of Cut, d (mm)	3	1.2

TABLE VII

OPTIMUM R_aVALUE (TNMG 160412)

Speed,v (m/min)	Feed, f (mm/rev)	Depth of Cut, d (mm)	R_a (optimized)
120	0.05	1.2	0.087

IV. ANALYSIS OF PERCENTAGE CONTRIBUTION USING ANOVA

The statistical analysis of variance or ANOVA was implemented for identifying the significance of each parameters contribution to surface roughness [9]. The analysis was carried out with one-way analysis of variance with 1% level of significance [7]. The statistical software Minitab-16 which was also used for Taguchi DOE was made use here. The results of each parameter versus the R_a value are given in the tables VIII, IX, X, XI, XII, XIII of which, tables VIII, IX and X correspond to the tool TNMG 160408 and tables XI, XII, XIII correspond to the tool TNMG 160412.

TABLE VIII

ONE-WAY ANOVA: R_a TNMG 160408 (KCP25)VERSUSSPEED

Source	DOF	SS	MS	F
Speed	2	0.000134	0.000067	0.07
Error	6	0.005809	0.000968	
Total	8	0.005943		

TABLE IX

ONE-WAY ANOVA: R_a TNMG 160408 (KCP25) VERSUS FEED

Source	DOF	SS	MS	F
Feed	2	0.001667	0.000833	1.17
Error	6	0.004276	0.000713	
Total	8	0.005943		

TABLE X

ONE-WAY ANOVA: R_a TNMG 160408 (KCP25) VERSUS DEPTH OF CUT

Source	DOF	SS	MS	F
Depth of Cut	2	0.001686	0.000843	1.19
Error	6	0.004257	0.000709	
Total	8	0.005943		

TABLE XI

ONE-WAY ANOVA: R_a TNMG 160412 (KP25) VERSUSSPEED

Source	DOF	SS	MS	F
Speed	2	0.002486	0.001243	1.44
Error	6	0.005164	0.000861	
Total	8	0.007650		

TABLE XII

ONE-WAY ANOVA: R_a TNMG 160412 (KP25) VERSUS FEED

Source	DOF	SS	MS	F
Feed	2	0.00086	0.00043	0.38
Error	6	0.00679	0.00113	
Total	8	0.00765		

TABLE XIII

ONE-WAY ANOVA: R_a TNMG 160412 (KP25)VERSUSDEPTH OF CUT

Source	DOF	SS	MS	F
Depth of Cut	2	0.002055	0.001027	1.10
Error	6	0.005595	0.000933	
Total	8	0.007650		

From the tables the abbrevations DOF, SS, MS and F correspond to Degree of Freedom, Sum of Squares, Mean Square and F-value. The percentage contribution of each parameter to the surface roughness is calculated by using the formula:

$$\text{Percentage Contribution} = \frac{SS\ Factor}{SS\ Total}$$

Thus the percentage contributions of the various parameters versus the roughness values calculated through one-way ANOVA and tabulated in tables VIII, IX, X, XI, XII, XIII are 2.25%, 28.05%, 28.37%, 32.5%, 11.31% and 26.86% respectively.

V. CONCLUSION

In this study, an investigation on the surface roughness based on the parameter design of the Taguchi method in the optimization of turning operations has been investigated and presented. Summarizing the mean experimental results of this study, the following generalized conclusions can be drawn:

Based on the Main effect plots of S/N Ratios and the associated R_a values obtained with each parameter combination, it is seen that, Surface roughness decreases with increase in cutting speed, decrease in feed rate and increase in depth of cut. However it is obvious that the tool life will decrease with increase in cutting speed and depth of cut. Hence it is necessary to arrive at a compromise between the tool life and surface finish (lesser surface roughness implies better surface finish)

Based on the analysis of variance (ANOVA) results, the highly effective parameters on both the surface roughness and tool life were determined. Namely, the feed rate and depth of cut with highest percentage contributions of 28.05%and 28.37% were found as the most influencing parameters (only consistent results were taken into consideration)

It was seen that use of a premium grade tool insert TNMG 160412 over TNMG 160408 indeed resulted in better surface finish which is about 26.27%

The best parameter levels for turning of the metal were found out using the main effects plot. The best parameters for

TNMG 160408 insert were: 120 m/min speed, 0.15 mm/rev feed and 1.2 mm Depth of Cut and for TNMG 160412, the best parameters were: 120 m/min cutting speed, 0.05 mm/rev feed rate and 1.2 mm depth of cut.

The optimized parameters provided significant improvement in surface finish. The improvement of surface finish from the worst set of parameters was 38.86% for TNMG 160408 insert and 50% for TNMG 160412 insert.

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