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Determination of Optimum Parameters in CNC Drilling of Aluminium Alloy Al6463 by Taguchi Method

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Abstract— In this paper the drilling of AL6463 aluminium alloy with the help of CNC drilling machine operation with Tool use high speed steel by applying Taguchi methodology has been reported. The purpose of this paper is to investigate the influence of cutting parameters, such as cutting speed and feed rate, and point angle on surface roughness, hole dia error and burr height produced when drilling AL6463 aluminium alloy. A plan of experiments, based on L9 Taguchi design method, was made and drilling was done with the selected cutting parameters. All tests were run at cutting speeds of 1250,1500 and 1750 r.p.m. and feed 25,50, and 75 mm/min and point angle of 90°, 118°, and 140°. The orthogonal array, signal-to-noise ratio, and analysis of variance (ANOVA) were employed to investigate the optimal drilling parameters.

Keywords: CNC Drilling, Taguchi Method, Surface Roughness, Hole dia error, Burr Height, S/N Ratio, ANOVA

I. INTRODUCTION

Amongst traditional machining processes, drilling is one of the most important metal cutting operations, comprising approximately 33% of all metal cutting operations. Drilling is a process of making holes or enlarging a hole in an object by forcing a rotating tool called drill. The same operation can be accomplished in some other machine by holding the drill stationary and rotating the work. The most general example of this class is drilling in lathe.

One of the most significant developments in production engineering over the last 20 years is the application of numerically controlled machine tools in production. No doubt, CNC application first started with “AEROSPACE” Industries to manufacture highly complex parts made of light alloys, requiring heavy metal removal. The CNC machine tools today have made considerable inroads to medium or large batch production in many metal working industries. The relatively high capital cost of CNC machines, further to be justified only by the “AEROSPACE” industries, is now being accepted by other industries because of the numerous direct & indirect benefits derived with their use. This write-up presents a brief out line of CNC machines and their inherent advantages in production.

- The first benefit offered by all forms of CNC machine tools is improved automation.
- The second major benefit of CNC technology is consistent and accurate work pieces.
- A third benefit offered by most forms of CNC machine tools is flexibility.

A. Speed:

In a drilling machine, the cutting speed is the speed at which the material is removed from the work piece due to the rotary motion given to the drill. In particular, this refers to the peripheral speed of a point on the surface of drill in contact with the work. It is expressed in metre per minute and can be calculated by using the following equation.

$$\boldsymbol{v} = \frac{\boldsymbol{\pi DN}}{\mathbf{1000}} \text{ m/min}$$

Where, V is the cutting speed in m/min
D is the diameter of the drill in mm, and N is the speed of revolution in r.p.m

B. Feed:

The feed in drilling machine refers to the axial distance moved by the drill in one revolution. It is expressed in mm per rev. It may also be expressed as m per min.

$$F = f. N \text{ mm/min}$$

Here, *F* is the feed in mm per minute, *f* is the feed in mm/rev and *N* is the spindle speed in r.p.m

C. Depth of cut:

The depth of cut in drilling refers to the radius of drill being used and is selected on the basis of hole diameter desired or required. It is expressed in mm and can be calculated from the following equation.

$$d = \frac{D}{2} \text{ in mm}$$

Where d is the depth of cut in mm, and
D is the diameter of the drill in mm

II. TAGUCHI METHOD

Competitive crisis in manufacturing during the 1970’s and 1980’s that gave rise to the modern quality movement, leading to the introduction of Taguchi methods to the U.S. in the 1980’s. Taguchi’s method is a system of design engineering to increase quality. Taguchi Methods refers to a collection of principles which make up the framework of a continually evolving approach to quality. Taguchi Methods of Quality Engineering design is built around three integral elements, the loss function, signal-to-noise ratio, and orthogonal arrays, which are each closely related to the definition of quality.

Taguchi method is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipment, and facilities. These improvements are aimed at improving the desired characteristics and simultaneously reducing the number of defects by studying the key variables controlling the process and optimizing the procedures or design to yield the best results. Taguchi proposed a standard procedure for applying his method for optimizing any process.

A. Orthogonal Arrays

An orthogonal array is a type of experiment where the columns for the independent variables are "orthogonal" to one another. Orthogonal arrays are employed to study the effect of several control factors. Orthogonal arrays are used to investigate quality. Orthogonal arrays are not unique to Taguchi. They were discovered considerably earlier (Bendell, 1998). However Taguchi has simplified their use by providing tabulated sets of standard orthogonal arrays and corresponding linear graphs to fit specific projects (ASI, 1989; Taguchi and Kenishi, 1987). A L_9 Orthogonal array is shown in the table 2.1

B. Selection of Orthogonal array

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 design parameters that need to be made to determine which level is better and specifically how much better it is. For example, a three-level design parameter counts for two degrees of freedom. The degrees of freedom associated with the interaction between two design parameters are given by the product of the degrees of freedom for the two design parameters.

Table 2.1: A L_9 Orthogonal array

Exp.No.	A	B	C
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

C. Signal-to-Noise Ratio

The signal-to-noise concept is closely related to the robustness of a product design. A Robust Design or product delivers strong 'signal'. It performs its expected function and can cope with variations ("noise"), both internal and external. In signal-to-Noise Ratio, signal represents the desirable value and noise represents the undesirable value.

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

1) Smaller-The-Better $S/N = -10 \log \left(\frac{1}{r}\sum_{i=1}^{r} y_i^2\right)$
2) Larger-The-Better $S/N = -10 \log \left(\frac{1}{r}\sum_{i=1}^{r} \frac{1}{y_i^2}\right)$
3) Nominal-The-Best $S/N = -10 \log \left(\frac{\mu^2}{\sigma^2}\right)$

D. Analysis of variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is 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.

Various terms in ANOVA are

- **i.** Sum of squares (SS)
- **ii.** Mean Squares (MS)
- **iii.** Percentage contribution

i. Sum of squares (SS)

$SS_T = SS_{Factors} + SS_{error}$

(Total variation) can be written as

$SS_T = \left(\sum_1^N y^2_i\right) - \frac{T}{N}$

Where $T=\sum y$, where y is responses

$SS_{Factors} = SS_A + SS_B + SS_C + SS_D$

Where A, B, C and D are Process parameters, Sum of squares of individual factors can be calculated as follows

$SS_A = \frac{(SSA_1)^2+(SSA_2)^2+(SSA_3)^2}{3} - \frac{T^2}{N}$

Similarly SS_B, SS_C and SS_D can be calculated.

ii. Mean of Squares (Variance)

$MS = \frac{Sum\ of\ squares\ (individual\ factor)}{Degres\ of\ freedom\ (individual\ factor)}$

Degree of freedom: A degree of freedom in a statistical sense is associated with each piece of information that is estimated from the data.

iii. Percentage Contribution of each parameter

The equation for calculating the % contribution of each factor is

$\%\ of\ Contribution = \frac{SS\ (Factor)}{SS\ (Total)}$

III. DESIGN OF EXPERIMENT

In this study, three machining parameters were selected as control factors, and each parameter was designed to have three levels, denoted 1, 2, and 3 (Table 3.1). The experimental design was according to an L9) array based on Taguchi method, while using the Taguchi orthogonal array would markedly reduce the number of experiments. A set of experiments designed using the Taguchi method was conducted to investigate the relation between the process parameters and Surface roughness, Hole dia error and Burr height. DESIGN EXPERT @ 16 minitab software was used for regression and graphical analysis of the obtained data.

Table3.1 Process parameters and their levels

Symbol	Parameter	Level 1	Level 2	Level 3
A	Spindle speed(rpm)	1250	1500	1750
B	Feed rate (mm/min)	25	50	75
C	Point angle	90˚	118˚	140˚

IV. EXPERIMENTAL WORK

The work piece material selected for investigation is the aluminium alloy AL6463. The chemical and mechanical properties of the work piece are shown in table 4.1 and 4.2 respectively.

Table 4.1: Chemical composition of Al 6463 alloy

Al	Mg	Si	Fe	Cu	Zn	Mn	Ti	Cr
95.8-98.5	0.45-0.9	0.20-0.6	0.35	0.10	0.25	0.15	0.15	0.04-0.35

Table 4.2: Mechanical properties of Al 6463 alloy

UTS(Mpa)	YS(Mpa)	Density (g/cm^3)	Elongation (%)	Hardness (Bhn)
310	276	2.7	12	95

Three HSS twist uncoated drills with 9.5 mm diameter and different point angles 90°, 118°, and 140° are used for the experiments.

Table 4.3: Design of experiments for drilling operations

Exp.No	Spindle Speed(rpm)	Feed Rate (mm/min)	Point Angle (degree)
1	1250	25	90
2	1250	50	118
3	1250	75	140
4	1500	25	140
5	1500	50	90
6	1500	75	118
7	1750	25	118
8	1750	50	140
9	1750	75	90

The experiments have conducted using different point angles 90°, 118°, and 140° and the work pieces after drilling operation are as shown in Fig 1. surface roughness, hole diametral error, and burr height were measured with the help of talysurf, digital calliper, and tool maker's microscope respectively. The average values of individual response for different point angles are shown in table 4.4

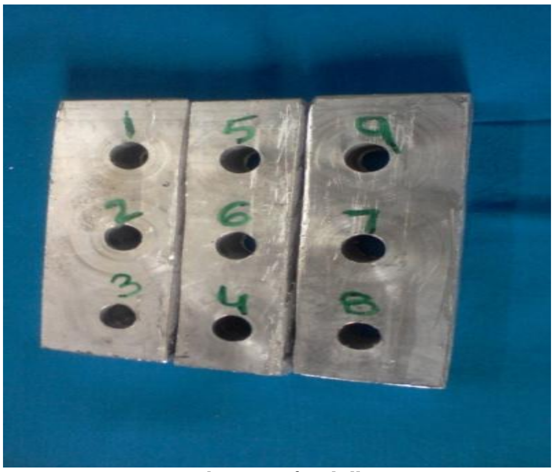

Figure 1: Work pieces after drilling operation

Table 4.4: Measured response values in drilling of Al 6463

Exp. No.	Surface roughness (Microns)	Hole diametral error (mm)	Burr height (mm)
1	3.47	0.07	1.79
2	2.16	0.03	0.84
3	3.28	0.04	0.92
4	4.12	0.11	0.85
5	3.94	0.14	0.89
6	3.08	0.02	0.62
7	1.33	0.05	0.94
8	1.47	0.04	0.83
9	2.36	0.08	1.92

V. RESULTS AND DISCUSSION

The response values are measured from the experiments and their corresponding S/N ratio are calculated by applying "lower the better" type.

S/N ratio for Smaller the better type Response is

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

Where r= Number of repetitions in a trail

A. Calculation of S/N ratio for the first experimental trial

i. S/N ratio for Surface roughness

For experiment i =1, $y_1 = 3.47$

Here only one repetition is considered in each experimental trail,

Hence r = 1 throughout all calculations of S/N ratio.

S /N = -10 log (3.47^2)
= -10 log (12.05)
= -10*1.0809 = -10.81.

ii.S/N ratio for Hole Diametral error

i =1, y_1 =0.07 and r =1

S /N = -10 log (0.07^2)
= -10 log (0.0049)
= -10*(-2.309) = 23.09.

iii.S/N ratio for Burr height

i =1, y_1 =1.79 and r =1

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$$S/N = -10 \log (1.97^2)$$
$$= -10 \log (3.2041)$$
$$= -10*(.506)$$
$$= -5.06.$$

Similarly S/N ratio for all experimental trails are calculated and shown in table 5.1

Table 5.1: S/N ratio values for Responses

Exp.No	Surface roughness (microns)	Hole diametral error (mm)	Burr height (mm)
1	-10.81	23.09	-5.06
2	-6.69	30.45	1.51
3	-10.32	27.96	0.72
4	-12.30	19.17	1.41
5	-11.91	17.08	1.01
6	-9.77	33.98	4.15
7	-2.48	26.02	0.54
8	-3.35	27.96	1.62
9	-7.45	21.94	-5.67

B. Determination of Optimal process parameters for surface roughness

Optimal levels of process parameters for individual responses are determined by S/N ratio analysis and the steps in analysis are as follows

i. Determination of Mean S/N ratio for each level of the parameters.
ii. Draw graph between Mean S/N ratio values and process parameter values.

i. Determination of Mean S/N ratio for each level of the parameters.

Mean S/N ratio for parameter A at level 1 can be calculated as follow

η_m= ((-10.81) + (-6.69) + (-10.32)) / 3 = -9.27.

Similarly the Mean S/N ratio values for each level of the parameters were calculated and shown in table 5.2

Table 5.2: Mean S/N Response table of Surface Roughness

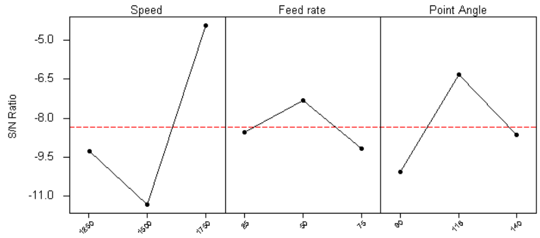
Levels	Speed	Feed	Point angle
1	-9.27	-8.53	-10.06
2	-11.33	-7.32	-6.31
3	-4.43	-9.18	-8.66
Overall mean (dB) = -8.343			

Table 5.3: Mean table of Surface Roughness

Levels	Speed	Feed	Point angle
1	2.97	2.97	3.25
2	3.71	2.52	2.19
3	1.72	2.91	2.95
Overall mean (γ) = 2.8			

The response graph between mean S/N ratio and process parameter levels is shown in graph 1

Main Effects Plot for S/N Ratios



Graph 1:S/N Response Graph of Surface roughness

From the above graph the optimal combination of process parameters is A_3 B_2 C_2

C. Determination of Optimal process parameters for hole diametral error

Following the above steps The Mean S/N ratio values for each level of the parameters is shown in table 5.4.

Table 5.4: Mean S/N Response table of Hole diametral error

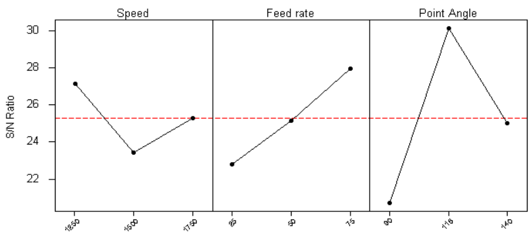
Levels	Speed	Feed	Point Angle
1	27.16	22.76	20.70
2	23.41	25.16	30.15
3	25.30	27.96	25.03
Overall mean (dB) = 25.29			

Table 5.6: Mean table of Hole diametral error

Levels	Speed	Feed	Point angle
1	0.046	0.076	0.096
2	0.090	0.070	0.033
3	0.056	0.046	0.063
Overall mean (γ) = 0.064			

The response graph between mean S/N ratio and process parameter levels is shown in graph 2.

Main Effects Plot for S/N Ratios



Graph 2: S/N Response Graph of Hole diametral error

From the above graph the optimal combination of process parameters is A_1 B_3 C_2

D. Determination of Optimal process parameters for burr height

The Mean S/N ratio values for each level of the parameters are shown in table 5.7.

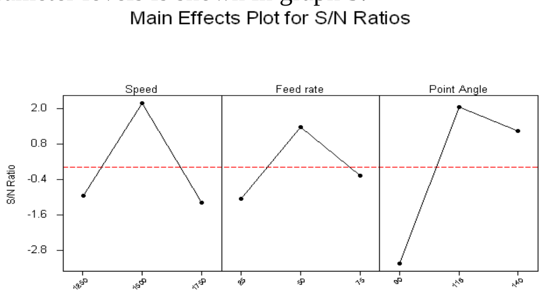
Table 5.7: Mean S/N Response table of Burr height

Levels	Speed	Feed	Point angle
1	-0.94	-1.04	-3.24
2	2.19	1.38	2.07
3	-1.17	-0.27	1.25
Overall mean (dB) = 0.08			

Table 5.8: Mean table of Burr height

Levels	Speed	Feed	Point angle
1	1.18	1.19	1.53
2	0.79	0.85	0.80
3	1.23	1.15	0.87
Overall mean (γ) = 1.07			

The response graph between mean S/N ratio and process parameter levels is shown in graph 3.



Graph 3: S/N Response Graph of Burr height

From the above graph the optimal combination of process parameters is A_2 B_2 C_2

Optimal process parameter levels for Responses are summarized in the following table 5.9.

Table 5.9: Optimal process parameter levels for Responses

S.No	Response	Optimal machining parameters
1	Surface roughness	A_3 B_2 C_2
2	Hole diametral error	A_1 B_3 C_2
3	Burr height	A_2 B_2 C_2

E. Contribution of Process parameters on Responses

Contribution of process parameters affecting responses are determined by performing ANOVA in MINITAB software and results are as follows.

It is observed from Table 12 the surface roughness is affected by the Spindle speed(A), Feed rate(B), Point angle(C) are 73.06%, 4.24%, 21.78% respectively. The percent numbers depict that the Spindle Speed and Point angle have significant effects on the Surface roughness.

Table 5.10: ANOVA of Surface roughness

Parameter	DF	SS	MS	F	P (%)
A	2	6.0884	3.0442	81.173	73.06
B	2	0.3538	0.1769	4.7173	4.24
C	2	1.8155	0.9077	21.205	21.78
Error	2	0.075	0.0375		0.90
Total	8	8.3327			

F. Contribution of Process parameters on Hole diametral error

It is observed from Table 5.11 the hole diametral error is affected by Spindle speed(A), Feed rate(B), Point angle(C) are 23.80%, 11.11% 47.46%, respectively. The percent numbers depict that the Point angle and Spindle speed have significant effects on the Hole diametral error.

Table 5.11: ANOVA of Hole diametral error

Parameter	DF	SS	MS	F	P (%)
A	2	0.003	0.0015	1.3636	23.80
B	2	0.0014	0.0007	0.6363	11.11
C	2	0.006	0.003	2.7272	47.61
Error	2	0.0022	0.001		17.46
Total	8	0.0126			

G. Contribution of Process parameters on Burr height

It is observed from Table 5.12 the burr height is affected by the Spindle speed(A), Feed rate(B), Point angle(C) are 21.26%, 12.37%, 58.93% respectively. The percent numbers depict that the Spindle Speed and Point angle have significant effects on the burr height.

Table 5.12: ANOVA of Burr height

Parameter	DF	SS	MS	F	P (%)
A	2	0.3560	0.1780	2.8617	21.26
B	2	0.2071	0.1035	1.6639	12.37
C	2	0.9866	0.4933	7.9308	58.93
Error	2	0.1243	0.0622		7.42
Total	8	1.6740			

Percentage contribution of process parameters on responses shown in figure 2

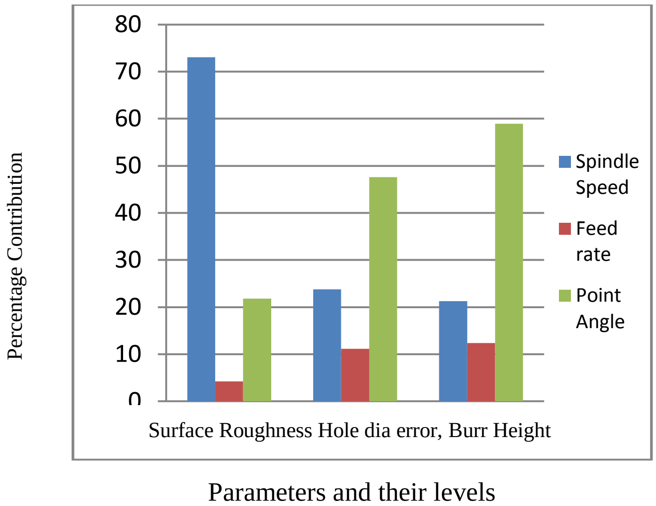


Figure 2: Percentage Contribution of Process Parameters on Responses

For achieving minimum surface roughness on the Aluminum alloy always higher cutting speeds and standard point angles are preferred and for achieving minimum hole diametral error and lower burr height always at lower cutting speeds and standard point angles are preferred.

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