An Experimental Investigation on Surface Roughness And Roundness of Hole In Drilling Process of Mild Steel Plate Using Taguchi Statistical Design of Approach

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Abstract- *Presently, almost half of the world's industrial and production is done by using mild steel. It is very easy to machine materials like mild because of their high strength, high ductility and high thermal conductivity. This paper discusses the experimental study on performance characteristics of IS:2644 Mild steel during CNC drilling process. Factors like point angle (deg), spindle speed (RPM),hole depth (mm) and feed rate (mm/Rev) affect the performance parameters such as the surface roughness and roundness of hole during drilling process. To get minimum surface roughness and maximum roundness, the best optimal level of parameters has to be chosen carefully. This paper presents the multi-objective optimization of drilling process parameters using Taguchi method in machining of IS:2644 Mild steel. The experiments are conducted based on Taguchi L9 orthogonal array by taking point angle (deg), spindle speed (RPM),hole depth (mm) and feed rate (mm/Rev) at three levels. The Taguchi based signal-to-noise ratio analysis is used to obtain the relation between the machining parameters and performance characteristics. The complete experimental results are discussed and presented in this paper.*

ANOVA (Analysis of variance) test was conducted to determine the percentage of contribution for each process parameters on drilling. The results indicate that depth of hole is the most significant factor for surface roughness while, spindle speed the most significant factor for hole roundness. This work is useful for selection optimized values of various controllable process parameters that minimize surface roughness and maximize hole roundness.

Keywords- CNC drilling, IS:2644 Mild steel, surface roughness, hole roundness, signal-to-noise ratio, Taguchi method and ANOVA.

I. INTRODUCTION

Drilling is most widely used for machining processes to produce the holes in various industrial parts. Drilling is a process of producing round holes in a solid material or enlarging existing holes with the help of multi-point cutting tools (drill bits). [1] Drilling is one of the widely used machining processes for various purposes. Nowadays it is frequently used in automotive, aircraft and aerospace and dies or mold industries, home appliances, and medical and electrical equipment industries. Thus, it needs to be cost-effective along with the assurance of the quality specifications within the experimental limit. In today's rapidly changing circumstances in manufacturing industries, applications of optimization techniques in metal cutting processes are essential for a manufacturing unit to respond efficiently to severe competitiveness and the increasing demand of the quality product in the market. Optimization methods in metal cutting processes, considered being a very important tool for continual improvement of output quality in products & processes . The quality of drill depends on cutting tool geometry, workpiece materials, and input parameters [2].

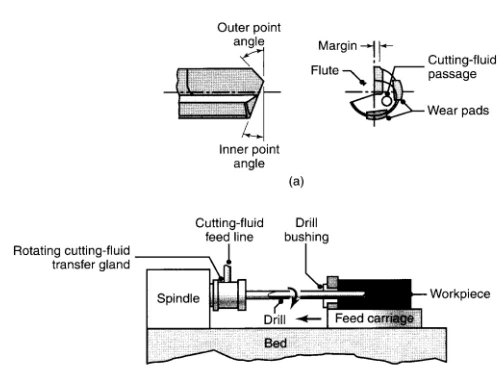


Fig. (a)A gun drill, showing various features;(b) Schematic illustration of the gun-drilling operation.

Drilling is one of the oldest metal removal processes. Also, 40% of metal removal processes in industries, majorly aerospace and automobile are done by drilling. Bottlenecks were major problem in the drilling of material using conventional method. However, the use of CNC, NC machines has made it very easy to drill without any kind of problem or bottlenecks. Also, the use of drills all over the industry shows the significance of drilling of material in each industry. AL-6061, Al- 6351 and AL-7075 were machined with feed rate, cutting speed and point angle as the parameters to optimize the effect on the diameter error and thrust force. And results showed that the cutting speed and feed rate both will help in minimizing the thrust force and diameter accuracy.

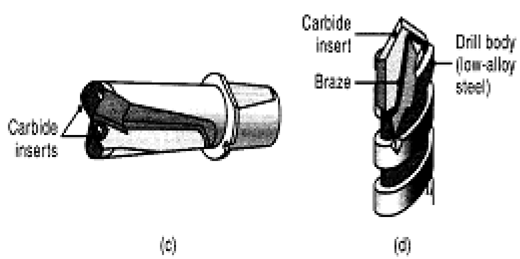
Cutting speeds in gun drilling are usually high, and feeds are low. Tolerances typically are about 0.025 mm. The cutting fluid is forced under high pressure through a longitudinal hole (passage) in the body of the drill Fig.(a). In addition to cooling and lubricating the workpiece, the fluid flushes out chips that otherwise would be trapped in the deep hole being drilled and thus interfere with the drilling operation. The tool does not have to be retracted to clear the chips, as is usually done with twist drills.[3]

II.DRILL MATERIALS AND SIZES

Drills usually are made of high-speed steels (M1, M7, and M10) and solid carbides or with carbide tips (typically made of K20 (C2) carbide), like those shown in Fig. (c) and (d). Drills are now commonly coated with titanium nitride or titanium carbo-nitride for increased wear resistance. Polycrystalline diamond- coated drills are used for producing fastener holes in fiber-reinforced plastics.

Because of their high wear resistance, several thousand holes can be drilled with little damage to the material.

In this experiment, the drill-bit diameter is 8mm ,while plate thickness is taken as 6 mm.[4]



II.A. SURFACE ROUGHNESS MEASUREMENT IN DRILLING

Surface roughness is defined as the finer irregularities of the surface texture that usually result from the inherent action of the machining process or material condition. A portable surface roughness tester (Model No TR 210 manufactured by Beijing TIME High Technology Ltd. Beijing City, China) has been used to measure surface roughness indicators of finished work pieces Fig.(e).

Fig.(e) Surface roughness tester

II.B. ROUNDNESS MEASUREMENT IN DRILLING

Roundness is measured using the Coordinate measuring machine (CMM). CMM has a vertical probe which moves up and down and along edges of the holes. The workpiece is placed flat on the table and the probe measures the roundness of the drilled hole. The machine used is Mitutoyo CRT-A C544 three-dimensional coordinate measuring machine (CMM) device. Minimum 10 points were measured to obtain the roundness of drilled hole Fig.(f).

Fig.(f) Coordinate Measuring Machine

III. WORK PIECE MATERIAL

In this experiment , the Work piece used was made of mild steel material ,which has the following chemical composition of mild steel workpiece as follows :

S.No.	Element	Composition (wt %)
1	C	0.0-0.07
2	Si	0.0-1.00
3	Mn	0.0-2.00
4	S	0.0-0.03
5	P	0.0-0.05
6	Ni	8.00-10.50
7	Cr	1.0-2.75
8	Mo	0.15-0.30
9	V	0.5-1.5
10	Cu	0.05-0.15
11	Fe	Rest/Balance

IV. MACHINE USED

This experiments were conducted on the VMC-400 machine. It is a vertical milling/drilling machine, which is manufactured by HMT. This vertical machining center is equipped with the Fanuc India series O-M controller for the execution of programs. The machine is capable of running at 4000rpm of spindle speed. The maximum feed that can be attained in this specific machine for this experiment is 2000mm/min.

Fig.(f) VMC400 vertical drilling machine

V. RANGE OF DIFFERENT PARAMETERS FOR OPTIMIZATION PURPOSE

The purpose of this paper is to fulfill the criteria of optimization under which the surface roughness and roundness of the hole , both to be optimized. There are some proper steps by which the surface roughness and roundness will be optimized are falls under this categories:

1. To make a list of parameter involved which are mostly responsible to affect the surface roughness and roundness.
2. Based on the experimental conditions, collect the data related with drilling process which is collected by orthogonal array and parameter level.
3. Now optimize the all individual parameter at the optimized level by the optimization techniques.
4. Verify the optimum settings result with the predicted result of surface roughness and roundness.
5. The process parameters of the drilling process can be listed as follows:
   - ➢ Spindle Speed (rpm)
   - ➢ Feed (mm/rev)
   - ➢ Point Angle (deg)
   - ➢ Depth of Hole(mm)

For each parameter during a process a range is decided between the different levels which optimize the parameter to a certain level and is acceptable in the manufacturing of a product of an organization for the purpose to increase the production rate. The parameters, along with their ranges and different levels are given in the following Table-(a).

Table-(a)Range of different Parameters

S.No.	Parameters	Range	Level -1	Level -2	Level -3
1.	Spindle Speed (rpm)	300-500	300	400	500
2.	Feed (mm/rev)	30-50	30	40	50
3.	Point Angle (deg)	90-118	90	104	118
4.	Depth of Hole(mm)	15-25	15	20	25

VI. TAGUCHI STATISTICAL DESIGN OF APPROACH

Dr.Genichi Taguchi introduced an optimization method that helped in making calculations of experiments easier and rapid. It was originally made to make the improvement in the quality of goods that were being made in japan. This technique helped in introducing a method that only require a specific set of experiments to find the effectiveness on the response parameters.[4]

Orthogonal Array represents the data structure and the matrix that it shows contains the data for the experiments.

In addition, the number of runs during experiment is defined by orthogonal array. In order to reach maximum quality of product three steps are very important in Taguchi method which is System Design, Parameter Design and tolerance design.[5]

Taguchi developed a special design of orthogonal arrays to study the entire parameter space with a small number of experiments only. The experimental results are then transformed into a signal-to-noise (S/N) ratio. It uses the S/N ratio as a measure of quality characteristics deviating from or nearing to the desired values. There are three categories of quality characteristics in the analysis of the S/N ratio, i.e. the lower the better, the higher the better, and the nominal the better. The formula used for calculating S/N ratio is given below.

- Smaller the better: It is used where the smaller value is desired.

$$\textbf{S/N Ratio}(\eta) = -10\log_{10}[\text{sum}(y_i^2/n)]$$

where y_i = observed response value and n = number of replications.

- Nominal the best: It is used where the nominal or target value and variation about

that value is minimum.

$$\textbf{S/N Ratio}(\eta) = -10\log_{10}(\mu^2/\sigma^2)$$

where μ = mean and σ = variance.

- Higher the better: It is used where the larger value is desired.

$$\textbf{S/N Ratio}(\eta) = -10\log_{10}[\text{sum}(y_i^2/n)]$$

where y_i = observed response value and n = number of replications.

VII. EXPERIMENTAL WORK

According to the method of Taguchi , Formation of an orthogonal array depends upon the number of control factors and interaction of interest. It also depends upon number of levels for the control factors of interest. Therefore with one control factor Spindle Speed (rpm) of three levels and other control factors, Feed , Point Angle and depth of hole, an orthogonal array is selected with 9 experimental runs and four columns. Taguchi has provided in the assignment of factors and interaction to arrays. The assigned L9 orthogonal array is shown in Table (b) and the experimental orthogonal array having their levels are assigned to columns is shown in Table (c).[6]

Table –(b) Orthogonal Array L9

Trail No.	A	B	C	D
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

A Table can also be drawn on the basis of above designed orthogonal array, which is shown in the Table(c) (also known as experimental orthogonal array L9)

Table –(c) Experimental Orthogonal Array L9

Trial No.	A	B	C	D
	Spindle Speed (rpm)	Feed (mm/rev)	Point Angle (deg)	Depth of Hole(mm)
1	300	30	90	15
2	300	40	104	20
3	300	50	118	25
4	400	30	104	25
5	400	40	118	15
6	400	50	90	20
7	500	30	118	20
8	500	40	90	25
9	500	50	104	15

VIII. RESULTS OF EXPERIMENT & S/N RATIO

The result of this experiments is obtained by conducting thrice for the same set of parameters using a single-repetition randomization technique .The hole roughness and roundness, that occur in each trial conditions were found and recorded. The average of the roughness and roundness values for the hole was also determined for each trial condition as shown in Table d and Table e . The roughness is “Smaller the better” type of quality characteristics, while roundness is “Higher the better” type of quality characteristics . The S/N ratios were computed for each of the 9 trials and for each affecting factors and the values are given in following Tables d and e respectively-

Table –(d) Surface roughness Table

Trial No.	A Spindle Speed (rpm)	B Feed (mm/rev)	C Point Angle (deg)	D Depth of Hole(mm)	Surface roughness	S/N Ratio
1	300	30	90	15	4.172	-12.406
2	300	40	104	20	6.162	-15.794
3	300	50	118	25	5.061	-14.084
4	400	30	104	25	6.330	-16.028
5	400	40	118	15	4.513	-13.089
6	400	50	90	20	6.624	-16.422
7	500	30	118	20	5.325	-14.526
8	500	40	90	25	7.440	-17.431
9	500	50	104	15	4.810	-13.642

Table –(e) Hole roundness Table

Trial No.	A Spindle Speed (rpm)	B Feed (mm/rev)	C Point Angle (deg)	D Depth of Hole(mm)	Roundness	S/N Ratio
1	300	30	90	15	15.235	-23.656
2	300	40	104	20	15.185	-23.628
3	300	50	118	25	15.237	-23.657
4	400	30	104	25	15.343	-23.718
5	400	40	118	15	15.286	-23.685
6	400	50	90	20	15.217	-23.646
7	500	30	118	20	15.457	-23.782
8	500	40	90	25	15.512	-23.813
9	500	50	104	15	15.017	-23.531

IX.A. MEAN EFFECT PLOTS TABLE FOR SURFACE ROUGHNESS

Table (f) for the mean effects plots for S/N Ratio is as Follows:

Level No.	Spindle Speed (rpm)	Mean S/N Ratio	Feed (mm/rev)	Mean S/N Ratio
1	300	-14.094	30	-14.320
2	400	-15.179	40	-15.438
3	500	-15.199	50	-14.716
Level No.	**Point Angle (deg)**	**Mean S/N Ratio**	**Depth of Hole (mm)**	**Mean S/N Ratio**
1	90	-13.045	15	-13.045
2	104	-15.580	20	-15.580
3	118	-15.847	25	-15.847

Table -(f) S/N Ratio for Surface Roughness

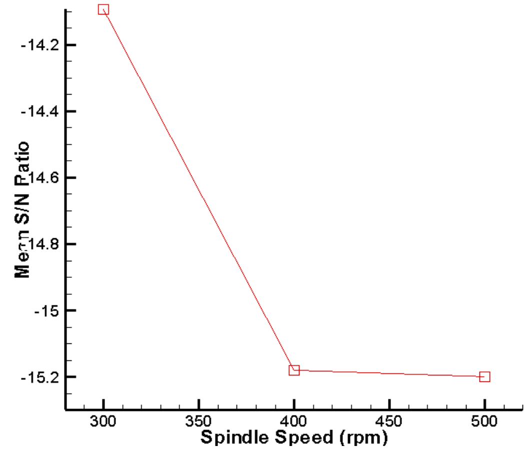


Fig. (g)spindle speed vs S/N Ratio

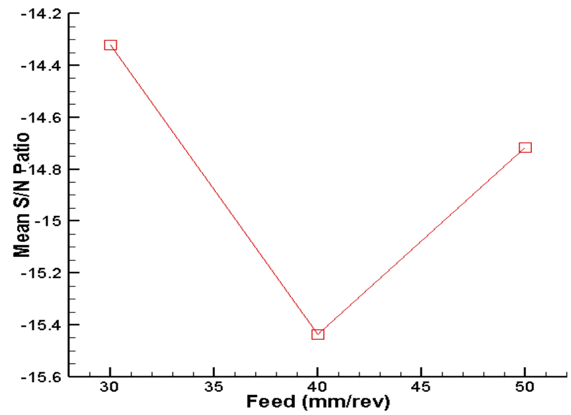


Fig. (h)feed vs S/N Ratio

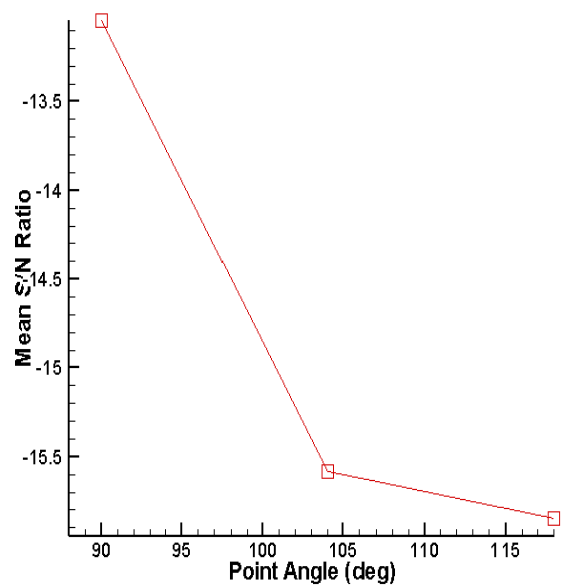


Fig. (i)Point angle vs S/N Ratio

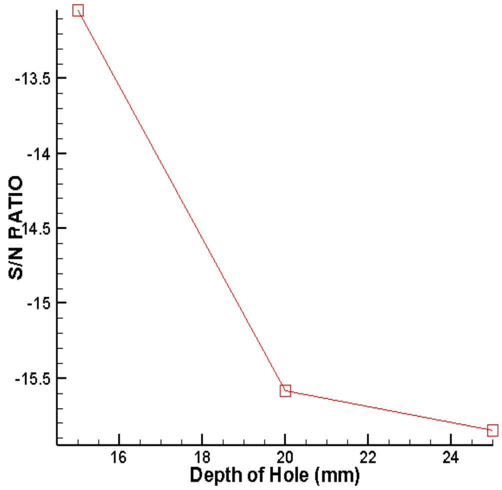


Fig. (j)Depth of hole vs S/N Ratio

IX.B. MEAN EFFECT PLOTS TABLE FOR HOLE ROUNDNESS

Table for the mean effects plots for S/N Ratio is as Follows:

Table -(g) S/N Ratio for Hole Roundness

Level No.	Spindle Speed (rpm)	Mean S/N Ratio	Feed (mm/rev)	Mean S/N Ratio
1	300	-23.647	30	-23.718
2	400	-23.683	40	-23.708
3	500	-23.708	50	-23.611
Level No.	**Point Angle (deg)**	**Mean S/N Ratio**	**Depth of Hole (mm)**	**Mean S/N Ratio**
1	90	-23.705	15	-23.624
2	104	-23.625	20	-23.685
3	118	-23.708	25	-23.729

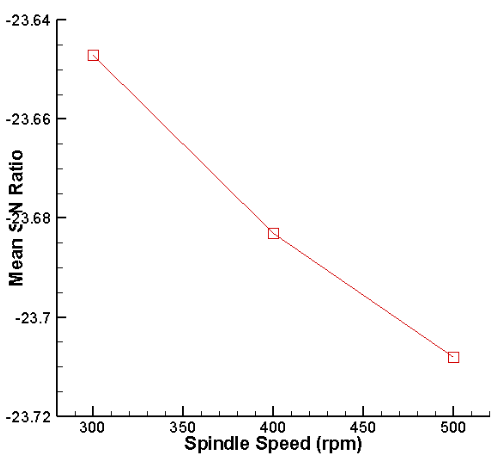


Fig. (k)spindle speed vs S/N Ratio

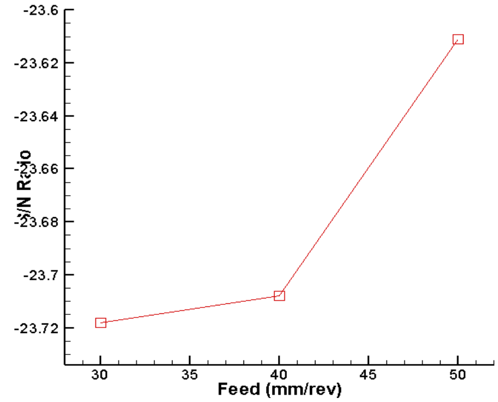


Fig. (l)feed vs S/N Ratio

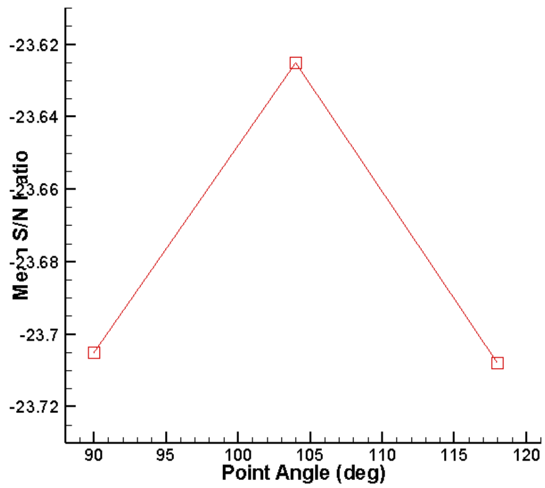


Fig. (m) Point angle vs S/N Ratio

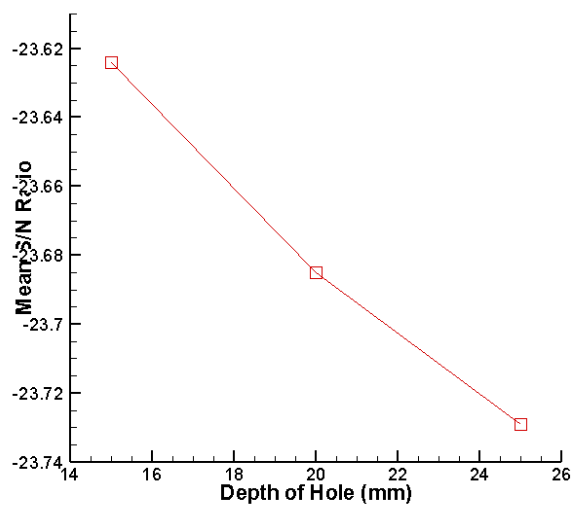


Fig. (n) Depth of hole vs S/N Ratio

X.A. COMPUTATION SCHEME OF PARETO ANOVA FOR SURFACE ROUGHNESS

The general scheme of computation of Pareto ANOVA was given in the Table (h). Pareto ANOVA computation was done by using the S/N ratios of the process parameters to predict the optimal parameter level combination as well to determine the most influencing process parameter involved in this study.[7]

Table (h) General Scheme for Pareto ANOVA computation:

Parameters		A	B	C	D	Total
SUM	1	ΣA_1	ΣB_1	ΣC_1	ΣD_1	$T= \Sigma A_1 + \Sigma A_2 + \Sigma A_3$
	2	ΣA_2	ΣB_2	ΣC_2	ΣD_2	
	3	ΣA_3	ΣB_3	ΣC_3	ΣD_3	
SSD		S_A	S_B	S_C	S_D	$S_T= S_A- S_B- S_C- S_D$
Degree of Freedom		2	2	2	2	8
Contribution Ratio		$(S_A/S_T)*100$	$(S_B/S_T)*100$	$(S_C/S_T)*100$	$(S_D/S_T)*100$	100

Where SSD stand for the sum of square of differences and its values is given as

$$S_A= (\Sigma A_1- \Sigma A_2)^2+(\Sigma A_2- \Sigma A_3)^2+(\Sigma A_3- \Sigma A_1)^2$$

Similarly we can calculate the values of S_A, S_B and S_C.

ΣA_1= Sum of S/N ratio for single parameter under three trial for same level -1.[7]

X.B. COMPUTATION SCHEME OF PARETO ANOVA FOR HOLE ROUNDNESS

The general scheme of computation of Pareto ANOVA was given in the Table (i). Pareto ANOVA computation was done by using the S/N ratios of the process parameters to predict the optimal parameter level combination as well to determine the most influencing process parameter involved in this study.

Table (i) General Scheme for Pareto ANOVA computation:

Parameters		A	B	C	D	Total
SUM	1	ΣA_1	ΣB_1	ΣC_1	ΣD_1	$T= \Sigma A_1 + \Sigma A_2 + \Sigma A_3$
	2	ΣA_2	ΣB_2	ΣC_2	ΣD_2	
	3	ΣA_3	ΣB_3	ΣC_3	ΣD_3	
SSD		S_A	S_B	S_C	S_D	$S_T= S_A- S_B- S_C- S_D$
Degree of Freedom		2	2	2	2	8
Contribution Ratio		$(S_A/S_T)*100$	$(S_B/S_T)*100$	$(S_C/S_T)*100$	$(S_D/S_T)*100$	100

Where SSD stand for the sum of square of differences and its values is given as

$$S_A= (\Sigma A_1- \Sigma A_2)^2+(\Sigma A_2- \Sigma A_3)^2+(\Sigma A_3- \Sigma A_1)^2$$

Similarly we can calculate the values of S_A, S_B and S_C.

ΣA_1= Sum of S/N ratio for single parameter under three trial for same level -1.[7]

XI.A. PARETO ANOVA COMPUTATION FOR SURFACE ROUGHNESS

Pareto ANOVA Computation for surface roughness is shown in the following table (j):

Table (j) Table Pareto ANOVA Computation for surface roughness

Parameters		A	B	C	D	Total
Sum at parameters levels	1	-42.284	-42.96	-46.259	-39.137	-133.422
	2	-45.539	-46.314	-45.464	-46.742	
	3	-45.599	-44.148	-41.699	-47.543	
SSD		21.587	17.352	35.601	129.138	203.678
Degree of Freedom		2	2	2	2	8
Contribution Ratio (%)		10.59	8.51	17.47	63.40	100

XI.B. PARETO ANOVA COMPUTATION FOR HOLE ROUNDNESS

Pareto ANOVA Computation for hole roundness is shown in the following table (k):

Table (k) Table Pareto ANOVA Computation for hole roundness

Parameters		A	B	C	D	Total
Sum at parameters levels	1	-70.941	-71.156	-71.115	-70.872	-213.116
	2	-71.049	-71.126	-70.877	-71.056	
	3	-71.126	-70.834	-71.124	-71.188	
SSD		0.0518	0.1898	0.1177	0.1511	0.5104
Degree of Freedom		2	2	2	2	8
Contribution Ratio (%)		10.14	37.18	23.06	29.60	100

XII. CONCLUSION

The optimum conditions for the parameter computed for the surface roughness in drilling process are given below as-

Spindle Speed (rpm) – level 3 – 500
Feed (mm/rev)– level 1 – 40
Point Angle (deg)– level 3 – 118
Depth of hole (mm)– level 3 – 25

The optimum conditions for the parameter computed for the hole roundness in drilling process are given below as-

Spindle Speed (rpm) – level 1 – 300
Feed (mm/rev)– level 3 – 50
Point Angle (deg)– level 2 – 104
Depth of hole (mm)– level 1 – 15

This also reflect that by using Taguchi method the factor levels when optimized will result in decrease of surface roughness and increase in the hole roundness ,also increase the yield percentage of the accepted drilled product without any additional investment. A usage of quality tools like pareto chart is useful for finding the minimum surface roughness in the daily operations of drilling. Quality of drilled hole can be improved by aesthetic look, dimensional accuracy, better understanding of noise factor and interaction between variables, quality cost system based on individual product, scrap reduction, reworking of drilling and process control.
From the ANOVA analysis , the results indicate that depth of hole is the most significant factor for surface roughness while, spindle speed the most significant factor for hole roundness.

X. FUTURE SCOPE

The present method adopted to solve the optimization problem of Drilling process is simple enough and is flexible in selection of objective functions for such manufacturing processes. During the solution of the problem, it has been found that the results obtained by the Taguchi method towards the exact solutions. This approach may be coupled to other optimization algorithms to get multistage multi-criterion optimization by Taguchi approach. Then this method will be able to show its importance in real life complex manufacturing problem solution.

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