An Experimental Study & Optimization of Drilling Process Parameters For Maximum Material Removal Rate Using Taguchi Method

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Abstract- *The main objective of this Experimental/research work was to optimize and analyzed process parameters namely point angle (deg), spindle speed (RPM), feed (mm/Rev) and Chisel edge width (mm) in drilling operation of mild steel. In this work, experiments were carried out as per the Taguchi experimental design and an L9 orthogonal array was applied to study the influence of various combinations of process parameters for MRR. ANOVA (Analysis of variance) test was conducted to determine the percentage of contribution for each process parameters on drilling. The results indicate that feed is the most significant factor and point angle is the second most significant factor for Material removal rate. This work is useful for selection optimized values of various controllable process parameters that do not only maximize the MRR but also reduce the delimitation and improve the MRR.*

Keywords- Drilling, DOE, Taguchi, ANOVA, Array, Mild Steel Plate, MRR.

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].

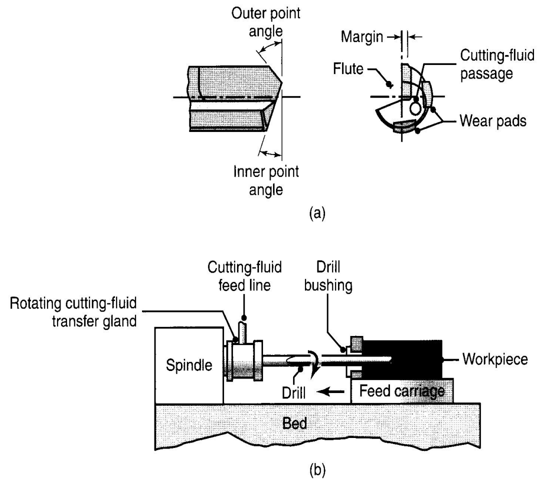


Fig. (a)A gun drill, showing various features;(b) Schematic illustration of the gun-drilling operation.

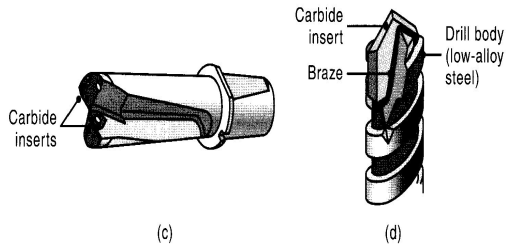
Cutting speeds in gun drilling are usually high, and feeds are low. Tolerances typically are about 0.025 mm. The cutting fluid is forced under high pressure through a longitudinal hole (passage) in the body of the drill (Fig. 23.22a). In addition to cooling and lubricating the workpiece, the fluid flushes 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]

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. MATERIAL-REMOVAL RATE IN DRILLING

The material-removal rate (MRR) in drilling is the volume of material removed per unit time. For a drill with a diameter D, the cross-sectional area of the drilled hole is $\pi D^2/4$. The velocity of the drill perpendicular to the work-piece is the product of the feed, f (the distance the drill penetrates per unit revolution), and the rotational speed, N, where N = V/π D. Thus,

$$MRR=(\pi/4)\,D^2.f.N$$

The dimensional accuracy of this equation can be checked, as was done for above equation by noting that MRR = $(mm^2)(mm/rev)(rev/min) = mm^3/min$, which is the correct unit for volume removed per unit time.

THRUST FORCE AND TORQUE

The thrust force in drilling acts perpendicular to the hole axis; if this force is excessive, it can cause the drill to bend or break. An excessive thrust force also can distort the workpiece, particularly if it does not have sufficient stiffness (for example, thin sheet-metal structures), or it can Cause the workpiece to slip into the work holding fixture.

The thrust force depends on factors such as (a) the strength of the workpiece material, (b) feed, (c) rotational speed, (d) drill diameter, (el drill geometry, and (f) cutting fluids. Accurate calculation of the thrust force on the drill is difficult. Thrust forces typically range from a few newtons for small drills to as high as 100 kN for drilling high-strength materials with large drills. Experimental data are available as an aid in the design and use of drills and drilling equipment.

A knowledge of the torque in drilling is essential for estimating the power requirement; however, because of the many factors involved, it is difficult to calculate. Torque can be estimated from the data by noting that the power dissipated during drilling is the product of torque and rotational speed and that we first have to calculate the material-removal rate. Torque in drilling can be as high as 4000 N.m.

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	0.17
2	Si	0.30
3	Mn	0.80
4	S	0.03
5	P	0.04
6	Ni	0.90
7	Cr	0.55
8	Mo	0.25
9	V	0.10
10	Cu	0.10
11	Fe	Rest/Balance

IV.METHODOLOGY

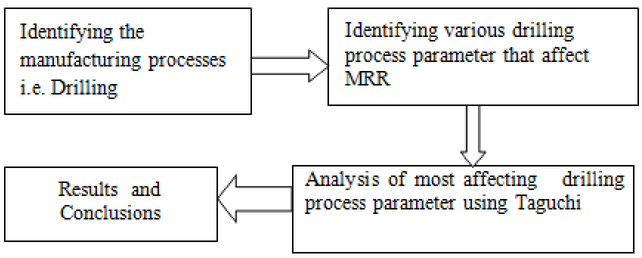


Fig. 1 METHODOLOGY

V. OPTIMIZATION OF PROCESS PARAMETERS TO MAXIMIZE THE METAL REMOVAL RATE

The purpose of this paper is to fulfill the criteria of optimization under which the MRR is to be increased. There are some proper steps by which the MRR will be optimized are falls under this categories:

1. To make a list of parameter involved which are mostly responsible to affect the MRR.
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 in the predicted result of metal removal rate.

5. The process parameters of the drilling process can be listed as follows:
   - Point Angle (deg)
   - Spindle Speed (rpm)
   - Feed (mm/rev)
   - Chisel edge width (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).

S.No.	Parameters	Range	Level-1	Level-2	Level-3
1.	Point Angle (deg)	75-115	75	95	115
2.	Spindle Speed (rpm)	500-1500	500	1000	1500
3.	Feed (mm/rev)	0.03-0.09	0.03	0.06	0.09
4.	Chisel edge width (mm)	0.8-1.8	0.8	1.3	1..8

VI. MEASUREMENT OF RATE OF MRR BY TAGUCHI METHOD

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.

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

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.

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

where μ = mean and σ = variance.

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

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

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

Taguchi suggested a standard procedure for optimizing any process parameters, The steps involved are:

- Determination of the quality characteristic to be optimized.
- Identification of the noise factors and test conditions.
- Identification of the control factors and their alternative levels.
- Designing the matrix experiment and defining the data analysis procedure.
- Conducting the matrix experiment.
- Analyzing the data and determining the optimum levels of control factors.
- Predicting the performance at these levels.

(A) Formation of Orthogonal Array L9

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 Point Angle of two levels and other control factors Spindle Speed, Feed and Chisel edge width and 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).

Table –(b) ORTHOGONAL ARRAY L9

Trail No.	W	X	Y	Z
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	1	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

(B) Experimental Orthogonal Array L9:

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

Trial No.	W	X	Y	Z
	Point Angle (deg)	Spindle Speed (rpm)	Feed (mm/rev)	Chisel edge width (mm)
1	75	500	0.03	0.8
2	75	1000	0.06	1.3
3	75	1500	0.09	1.8
4	95	500	0.03	1.8
5	95	1000	0.09	0.8
6	95	1500	0.03	1.3
7	115	500	0.09	1.3
8	115	1000	0.03	1.8
9	115	1500	0.06	0.8

Table –(c) EXPERIMENTAL ORTHOGONAL ARRAY L9

VII. 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 Metal Removal Rate (MRR), that occur in each trial conditions were found and recorded. The average of the Metal Removal Rate (MRR), was also determined for each trial condition as shown in Table 4. The Metal Removal Rate (MRR) is "Higher the better" type of quality characteristics. Higher the better S/N ratios were computed for each of the 9 trials and the values are given in Table (d):

Trial No.	Point Angle (deg)	Spindle Speed (rpm)	Feed (mm/rev)	Chisel edge width (mm)	MRR(mm^3/min)	S/N Ratio
1	75	500	0.03	0.8	753.6	-57.54
2	75	1000	0.06	1.3	3014.4	-69.58
3	75	1500	0.09	1.8	6782.4	-76.63
4	95	500	0.03	1.8	828.96	-58.37
5	95	1000	0.09	0.8	4521.6	-73.11
6	95	1500	0.03	1.3	2260.8	-67.08
7	115	500	0.09	1.3	2712.96	-68.67
8	115	1000	0.03	1.8	1507.2	-63.56
9	115	1500	0.06	0.8	5425.92	-74.69

Table (d): Metal Removal Rate (MRR) and Signal to Noise (S/N) Ratio against Trial Number

In the above table, from Taguchi Method ,the S/N ratio is maximum for the trial no. 3

VIII. MEAN EFFECT PLOTS TABLE FOR S/N RATIO

The table for the mean effects of various parameters on the S/N Ratio is given in the following table-

Level No.	Point Angle (deg)	Mean S/N Ratio	Spindle Speed (rpm)	Mean S/N Ratio
1	75	-67.92	500	-61.53
2	95	-66.12	1000	-68.75
3	115	-68.97	1500	-72.80
Level No.	**Feed (mm/rev)**	**Mean S/N Ratio**	**Chisel edge width (mm)**	**Mean S/N Ratio**
1	0.03	-61.64	0.8	-68.45
2	0.06	-72.14	1.3	-68.44
3	0.09	-72.80	1.8	-66.19

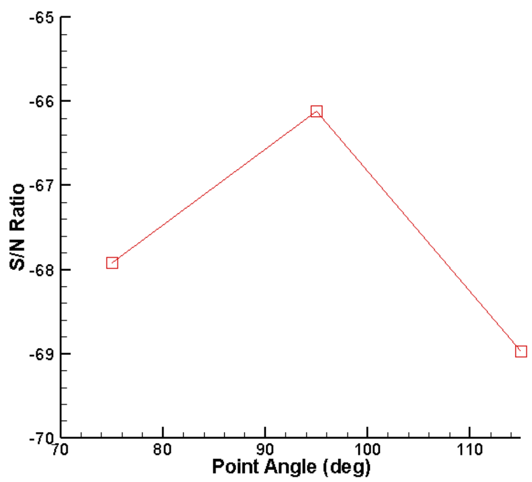


Fig.(a)

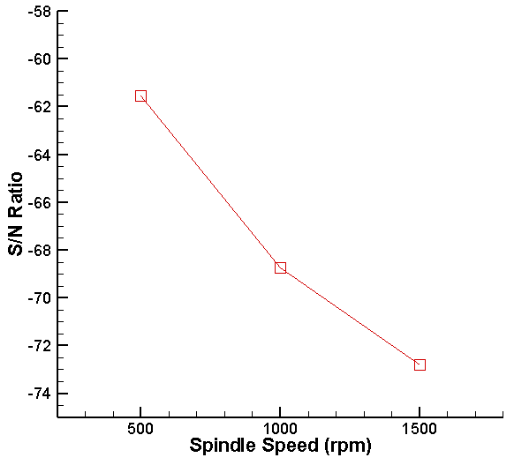


Fig.(b)

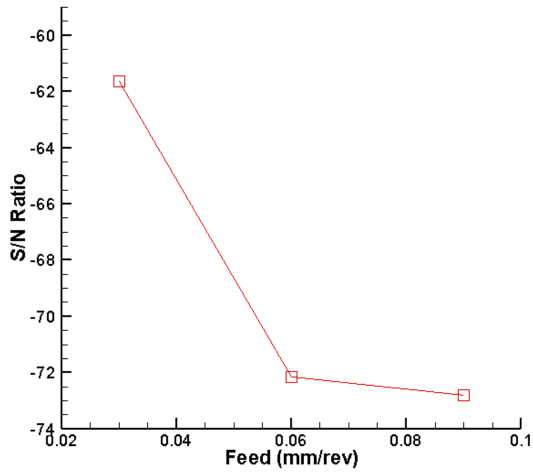


Fig.(c)

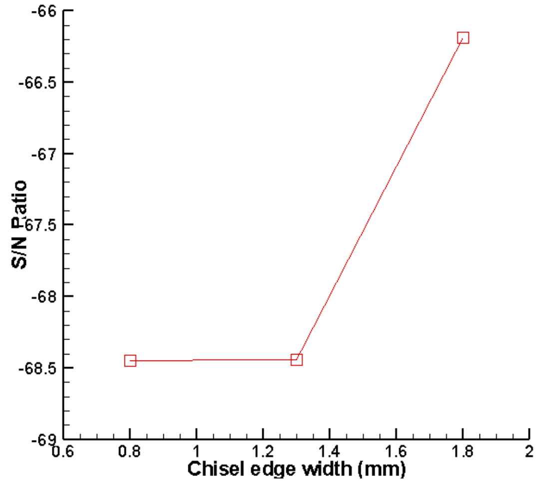


Fig.(d)

Fig.7- (S/N) Ratio v/s different drilling process properties referring fig (a),(b),(c) and (d).

IX. CONCLUSION

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

Point Angle (deg)– level 1 – 75

Spindle Speed (rpm) – level 3 – 1500

Feed (mm/rev)– level 3 – 0.09

Chisel edge width (mm)– level 3 – 1.8

The improvement expected in maximization of the material-removal rate (MRR) is 88.88% which means the material-removal rate (MRR) is optimized at the maximum extent of 88.88%. This also reflect that by using Taguchi method the factor levels when optimized will result in increase of material-removal rate and 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 maximum MRR 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.

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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