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Parametric Optimization of CNC Drilling Machine for HT Steel Using Taguchi Technique

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Abstract **This paper focused on optimizing drilling parameters based on Taguchi method for maximizing material removal rate (MRR). The experiments were conducted on CNC Drilling machine using HSS tool on material HT IS2062 E-350 steel at KEC International Limited, Jaipur. Drilling is the fundamental operation of making a cylindrical hole in metal cutting industry. Production of a large number of products within minimum time is the objective of every industry. The objective of present work is to optimize process parameter to be specific Cutting speed, Feed and Hole diameter. Three cutting parameters such as Spindle speed (217, 260, 310) in rpm, feed rate (50, 70, 100) in mm/min and hole diameter (18.5, 22.5, 26.5) in mm each at three levels were considered. Experimentation was completed according to Taguchi trial. The L9 orthogonal array be utilize to study the control of different combinations of process parameter on the hole quality. The analysis is made with the help of a software package *MINITAB* 16. As a result it was found that the hole dia. was the most significant factor on the MRR. This data can used by industry to increase drilling process capabilities.**

Keywords — CNC Drilling Machine, HT Steel, Taguchi Method, Material Removal rate (MRR)

I. INTRODUCTION

Drilling can be described as a process where a multipoint tool is used to remove unwanted materials to produce a desired hole. Drilling machines are highly used in an industry for metal removal operation. It is therefore essential to optimize quality and productivity. Taguchi design is proved to be an efficient tool to produce high quality products at very low cost. Taguchi's parameter design offers a systematic approach for optimization of various parameters with regard to performance quality and cost. The quality and cost is one of the prime requirements of customers for machined parts productivity is also necessary to full fill the customers demand. For this purpose quality of a product and productivity should be high and cost should be low. The signal to noise ratio in Taguchi methodology was used to find optimal parameters for MRR in drilling operation based experimental results done on High tensile steel work piece and high speed steel tool. Impact of drilling parameter such as speed (217, 260, 310) in r.p.m., feed rates (50, 70, 100) mm/min, hole diameter (18.5, 22.5, 26.5) in mm. The tool angle is constant is 118º. The analysis is made with the help of a software package MINITAB 16. A series of experiment based on Taguchi L9 orthogonal array is utilized for experimental planning for drilling machining. The main objective of project are to study the effect of process parameters on MRR and find the optimum conditions of cutting speed, feed rate and hole diameter using Taguchi's method of Design of experiment (DOE). The problem faced by production department in drilling process is that they knows only range of processing parameters within which the machine can do work on HT sections but they don't know the best value of parameters and combination of parameters. If no accurate data available, the operator need more time to setting up processing parameter to get holes. For this study spindle speed, feed rate and Hole diameter parameters involved in producing holes

II. PROJECT METHODOLOGY

A. *Taguchi Method*

Since 1960, Taguchi method has been used for improving the quality of Japanese products with great success. During the 1980's many companies finally realized that the old method of ensuring quality were not competitive with the Japanese method. The old methods for quality assurance relied heavily upon inspecting products as they rolled off the production line and rejecting those products that did not fall within a certain acceptance range. However, Taguchi was quick to point out that no amount of inspection can improve product quality and design robustness. Robust design is an engineering methodology for improving productivity during research and development so that high quality products can be produced quickly and at low cost. The idea behind robust design is to improve the quality of a product by minimizing the effect of vibration without eliminating the causes (since

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they are too difficult or too expensive to control). His method is an offline quality control method that is instituted at both the product and process design stage to improve product manufacturability and reliability by making product incentives to environmentally conditions and component variations. The end result is an robust design, that has an minimum sensitivity to variations in uncontrollable factors. Taguchi techniques for quality engineers is intended as a guide and a reference source for industrial practitioners (managers, engineers and scientists) involved in product or process experimentations and development. Most engineers are familiar with setting up test to model actual field conditions and the cause effect relationship of design to performance.

The first phase of the design strategy is the concept design. This phase include the gathering of technical knowledge and experiences to help the designer for selecting the most suitable one for the product. Parameter design, determined the best setting of control factors. This step is important, but it does not affect the unit manufacturing cost of the intended product. After the completion of parameter design step, the third step is performed. This third phase focuses on trade-off between the cost and quality. In Taguchi method to convert the trial result data into a value for the characteristic for analyze the optimum setting instead of average the signal-to-noise (S/N) ratio is uses. The S/N ratio thinks of both the variation and the average of the quality characteristic. The standard S/N ratios generally used are higher (larger) the better (HB), lower (smaller) the better (LB) and Nominal is best (NB). The parameter combination which gives highest S/N ratio is the optimal setting.

(i) Larger the Better - S/N ratio for larger the better type characteristic is calculated as follows

$$S/N\ ratio\ (\eta) = -10\log_{10}\left(\frac{1}{n}\sum\frac{1}{y_i^2}\right)$$

Where i = 1 to n

Where n = number of replications

Where y = output value

For the problems where maximization of the quality characteristic of interest is better, S/N ratios for larger is better is determined like tensile strength and material removal rate etc.

(ii) Smaller the better - S/N ratio for smaller the better type characteristic is calculated as follows

$$\mathrm{S/N\ ratio}(\eta) = -10\log_{10}\left(\frac{1}{n}\sum y_i^2\right)$$

Where i = 1 to n

Where n = number of replications

Where y = output value

In smaller the better type problems minimization of the characteristic is intended. This is usually the chosen S/N ratio for all undesirable characteristics like defects, surface roughness etc. for which the ideal value is zero.

(iii) Nominal the best - S/N ratio for nominal the best type characteristic is calculated as follows

$$\mathrm{S/N\ ratio}(\eta) = -10\log_{10}\left(\frac{\mu^2}{\sigma^2}\right)$$

Where μ = mean

σ = standard deviation

This case arises when a specified value is most desired, meaning that neither a smaller nor a larger value is desirable. In a nominal-the-best type of problem we try to minimize the mean squared error around the specific target value. Examples are insulation on a pipe, coating of materials and mixing of chemical solutions.

B. Orthogonal Array

Orthogonal Array is a mathematical tool to study a large number of process variables with a small number of experiments. It is called “Fractional factorial Design ". Which are symmetrical sub sets of all combinations of treatments in the corresponding full factorial design (When all levels of the factors are taken into consideration one by one). If experiments are conducted by taking one level of each parameter at a time, then it will a very time consuming and expensive process. Another disadvantage of one parameter at a time approach is that it fails to consider any possible interaction between the parameters. An interaction is the failure of one parameter to produce the same effect on the response at different levels of other parameter. Orthogonally means that factors can be evaluated independently of one another and the effect of one factor does not bother the estimation of the effect of another factor. Orthogonally is a balance experiment in which an equal number of samples under the various treatment conditions.

The column of the array are mutually orthogonal, means that for any pairs of column. All combinations of factor levels occur and it occur an equal number of times. This is called the balancing property. In an Orthogonal Array the number of rows represents the number of experiments. The number of columns of an array represents the maximum number of factors that can be analyzed using that array. There is a large variety of industrial experiments and each experiment has a different number of factors, which have two levels, three levels and some even more. Taguchi has tabulated 18 basic orthogonal array. It is called orthogonal arrays.

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III. DESIGN OF EXPERIMENT

C. Selection of Factor levels and Orthogonal Array Orthogonal Array

For this research three levels for three factors are selected. Table I shows Levels and Selected Factors.

TABLE I. LEVELS AND SELECTED FACTORS

Sl. No.	*Spindle speed (rpm)*	*Feed rate (mm/min)*	*Hole dia (mm)*
1	217	50	18.5
2	260	70	22.5
3	310	100	26.5

In an L9 orthogonal array three levels of each factor are considered where the selection of the array is because of its suitability for three factors with three Levels. The L9 orthogonal array is shown in Table II.

TABLE II. L9 ORTHOGONAL ARRAY FOR THREE FACTOR THREE LEVEL

TRIAL NO.	COLUMN NO.		
	A	*B*	*C*
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

D. CNC Drilling Machine

The tests are conducted on FICEP DB - 363 CNC Drilling Machine

Fig. 1. CNC Drilling Machine.jpg

Fig. 2. CNC Driling Machine.jpg

E. Work Piece Material

Drilling operation will be performed on High Tensile work Piece. The composition of High tensile steel (E350 grade) is C (0.2%), MN (1.55%), S (0.045%), P (0.045%), Si (0.45%). A HT Steel angle grade of IS 2062 E 350 of size 200 mm x 200 mm x 16 mm is used for drilling operation. Mechanical Properties of HT E350 steel is Tensile strength (490 Mpa), Yield stress (330 Mpa)

Fig. 3. Work Piece Material.jpg

F. Drill Tool

One of our tools for the CNC drilling operation will be the high speed steel. High speed steel (HSS) are used for making drilling tools, we used drill point angle is 118º. This property allows HSS to drill faster than high carbon steel. HSS contains high hardness composition are carbon (0.6% to 0.75 %), Tungsten (14% to 20%), Chromium (3% to 5%), Vanadium (1% to 1.5%), Cobalt (5% to 10%) and remaining is iron.

Fig. 4. Drill Tool.jpg

G. Plan Of Experiment

A HT Angle of size 200mm x 200mm x 16mm. In its flange 9 holes are drilled of 18.5 mm, 22.5 mm & 26.5 mm

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diameter. The experiments were conducted according to Taguchi's Orthogonal Array (OA). Which helps in reducing the number of experiments? In this report 3 parameter and 3 levels considered for experimental runs. Optimization for quality was carried out with Signal to Noise ration.

IV. EXPERIMENTAL WORK

H. Conduct Tests Described by Trials in Orthogonal Array

The tests are conducted on FICEP DB–363 CNC Drilling Machine according to the sets of control factors obtained from trials of orthogonal array. The control factors and levels of control factors according to orthogonal array are shown in Table III.

TABLE III. CONTROL FACTORS AND LEVELS

No. of Trial	Control Parameters		
	A	B	C
	Spindle Speed (rpm)	*Feed Rate (mm/min)*	*Hole Dia (mm)*
1	217	50	18.5
2	217	70	22.5
3	217	100	26.5
4	260	50	22.5
5	260	70	26.5
6	260	100	18.5
7	310	50	26.5
8	310	70	18.5
9	310	100	22.5

I. Result analysis of material removal rate

The MRR of each test produced according to trials of Orthogonal Array is shown in TABLE IV.

J. Calculation of S/N ratio for each ratio

The material removal rate can be calculated by considering weight and volume. For this study material removal rate is calculated by considering volume. By measuring Length, width and depth of each cut material removal rate is calculated. The MRR obtained is used to calculate the signal-to-noise (S/N) ratio to obtain the best setting of the parameters arrangement. MRR should be high therefore, the S/N ratio is calculated for larger the better. For calculating S/N ratio for this case of larger the better Taguchi has outlined an equation. The equation to obtain the values of S/N ratio is shown below.

S/N = -10log10 (MSD)

For larger is better

$$MSD = \frac{1}{n}\sum_{i=1}^{i=n}\frac{1}{{y_i}^2}$$

MSD = Mean Square Deviation

y = Surface Roughness value

n = No. of repetitions

S/N Ratio for trial no. 1

n = 1, y_1 = 1.495

$$S/_{N1}\ Ratio = -10\log_{10}\frac{1}{1}\left(\frac{1}{1.495^2}\right)$$

$$S/_{N1}\ Ratio = 3.4936$$

TABLE IV. S/N RATION FOR EACH TRIAL FOR MRR

Trial No.	*S.S. rpm*	*F.R. mm /min*	*Hole Dia mm*	*MRR gm /sec*	*S/N Ratio*
1	217	50	18.5	1.495	3.4936
2	217	70	22.5	3.054	9.6984
3	217	100	26.5	3.248	10.2312
4	260	50	22.5	2.338	7.3754
5	260	70	26.5	3.403	10.6371
6	260	100	18.5	2.527	8.0526
7	310	50	26.5	3.408	10.6499
8	310	70	18.5	2.197	6.8360
9	310	100	22.5	3.589	11.0984

K. Calculation of S/N ratio for each level of each factor

S/N ratio of level 1 for spindle speed, 217 rpm is obtained as follows :-

$$For\ Level\ 1 = \frac{(3.4936 + 9.6984 + 10.2312)}{3}$$

= 7.808

Similarly the S/N ratio for each level of each factor is obtained, and the results of S/N ratio for each level are shown in table V.

TABLE V. RESPONSE TABLE OF S/N RATIO FOR EACH LEVEL OF EACH FACTOR

LEVEL	*Spindle Speed*	*Feed Rate*	*Hole Dia.*
1	7.808	7.173	6.127
2	8.688	9.057	9.391
3	9.528	9.794	10.506
DELTA	1.72	2.621	4.379
RANK	3	2	1

The material removal rate data is also analysed by using the Minitab 16 software. The results obtained by Minitab 16 are shown in Fig.3

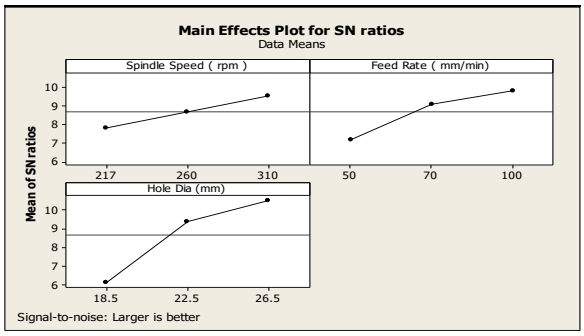

Fig. 5. Main effect plot for S/N ratio for MRR.jpg

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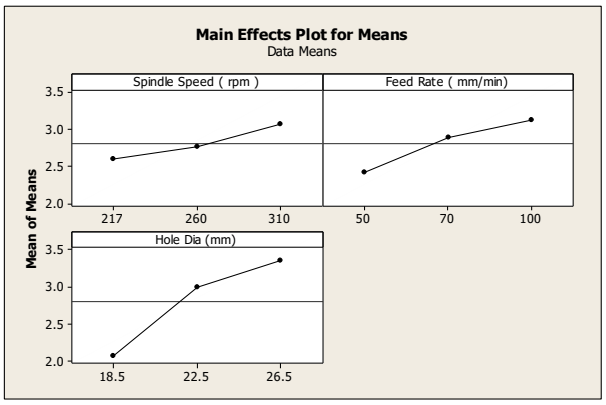

Fig. 6. Main effect plot for mean

From the S/N ratio response as shown in Table V the best combination of parameters are spindle speed (A) followed by feed rate (B) and hole dia. (C) can be represented by $A_3B_3C_3$. Table VI shows the summary of best combinations of parameters setting.

TABLE VI. BEST PARAMETERS SETTING FOR MRR

Factors	*Values*
Spindle Speed	310 rpm
Feed rate	100 mm/min
Hole Dia.	26.5 mm

V. CONCLUSION

In this study the Taguchi Technique was used to find optimum parameters in drilling of HT IS 2062 E-350, 200x200x16 Angle. The optimum level of the control factors to obtain better Material removal rate are : Spindle Speed (A_3, 310 rpm), Feed Rate (B_3, 100 mm/min), Hole Dia (C_3, 26.5 mm). We can conclude that the whole dia. mainly affects the MRR.

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