Taguchi based Approach for Parametric Optimization of Multi Response Factors in Micro Drilling Operation

Ashish Bharti and S. K. Moulick

Bhilai Institute of Technology, Durg, CG

Abstract: This paper presents the case study to find the optimized multi response factors for micro drilling operation. Drilling operation is influenced by spindle speed, feed rate, tool point angle, presence of coolant & lubricating agent, vibration, tool material, clearance and chip length. In this case study the Machining parameters spindle speed, feed rate and tool point is analyzed for their effect on the hole diameter produced and the material removal rate. Taguchi based method along with ANOVA (Analysis of Variance) and DOE (Design of Experiments) is implemented for optimized result . Drilling operation was done by 1mm(1/64 inch) drill bit with different combination spindle speed, feed rate and tool point angle. hole produced by drilling is measured using optical imaging microscope and material removal rate is calculated. Signal to Noise Ratio (SNR), Orthogonal Array L_9 is implemented for experimental layout and data obtained is used as output response in micro drilling Statical Software Minitab 15 is used for calculated the SNR value And result is drawn by ANOVA.

Keywords: Design of Experiments (DOE), Analysis of Variance(ANOVA), Signal to Noise (SNR) ratio, Micro drilling.

INTRODUCTION

1.1. Micro-drilling

Drilling is process of cutting holes of circular cross section in solid material by rotating multi point cutting tool. The bit is pressed against the work piece and rotated at rate of hundred to thousand of revolutions per minute. This forces the cutting edge against the work-piece, cutting off chips from what will become the hole being drilled.

Micro-drilling can be defined as the creation of very small holes 0.5 millimeters or less in a suitable material. This technology has been created and continues to be developed as parts and systems are miniaturized and new products are created, especially in the electronics, medical and industrial process industries. The process differs from conventional drilling not only in the size of the holes, but in the methods used to drill them.

Micro-drilling is done using a technique, where the drill bit is repeatedly applied to the work piece and then pulled back in order to clear debris from the hole.

A good example of micro drilling application is in fabrication of filter for a medical device. The filter consists of a titanium plate with 400 micro-drilled holes. Other applications is circuit boards for computers, which require very small holes to allow components to be installed. Any sort of product made with lithographic processes or electroplating benefits from this technique, which is capable of drilling holes meeting extreme tolerances for depth, diameter and smoothness.

1.2. Factors Affecting Micro Drilling

Tool Material: Tool material has significant impact on the quality of hole produced as different tool material have different wear resistance thus the quality of hole produced has different surface finish 2.

Tool geometry: Tool geometry very much affects the hole quality produced. The land is the area remaining after flute. Land creates friction with hole wall and generates heat. To reduce the surface of land in contact with work-piece drill bits are margin relieved. The amount of land remaining in contact with the hole wall during the drilling is referred to as margin. the wider the margin ,greater the friction area and the higher the drilling temperature ,resulting in higher extend of heat related hole quality defects such resin smear and plowing (furrows in resins).

Tool point angle has major impact on the hole quality. The larger tool point requires greater force to perform drilling operation but quality of hole surface is not compromised. Also larger included point angle provides more strength at the drill point.

Coolant & lubricant: Presence of coolant and lubricant also effects the quality of hole produced. The cutting temperature directly influences the hole sensitivity hole diameter, perpendicularity and the circularity, surface roughness and the tool wear since material properties such as shear strength and hardness are influenced by temperature the physical nature of metal removal process is highly dependent on temperature.

Vibration and Sound

Vibration is widely used for condition monitoring of rotating machinery. However, vibration has not been used to the same extent in tool condition monitoring, probably because as a method it is rather sensitive to noise which is present in cutting processes. The vibration signals are considered to contain reliable features for monitoring drill wear and breakage

Spindle Motor and Feed Drive Current

Spindle motor current is in principle measure feature as torque, i.e. they both enlighten how much power is used in the cutting process and they both also advise about the dynamics of cutting. Torque is a more sensitive way to measure than spindle motor current since the torque sensor is located close to the cutting tool and However, measuring torque is more complicated than measuring the current of the spindle motor and therefore the measurement of the current has also been widely tested and used.

LITRATURE REVIEW

Dong-Woo Kim *et al.* [1] reported minimization of thrust forces in the step-feed micro drilling process and establish relationship between feed rate, step-feed, and spindle rpm with that of drilling Thrust.

Azlan Abdul Rahman *et al.* [2] investigated the effect of feed rate, Spindle Speed, Drill bit diameter on material removal rate, Surface roughness, burr and dimensional accuracy. Experimental result shows the increment of spindle speed and feed rate value mostly affects the tool wear and size of burr on the drilled hole edges.

Hyon-ko-Sim *et al.* [3] has conducted a study on condition monitoring process on glass by using machine. It was found that Positional errors of fine holes, shape of cracks, and quality of hole surfaces are influenced by drilling conditions.

R. Vimal *et al.* [4] has Modeled and analyzed the Thrust force and Torque in drilling GFRP composites by multifaceted drill using fuzzy logic to indicate thrust force and torque in drilling of GFRP composites. The results suggested that the model can be effectively used for predicting the response variable by means of which delimitation can be controlled.

Yu Teng Liang *et al.* [5] has investigated the various Micro Machining Cutting Parameters of PMMA Polymer Material Using Taguchi's Method and applied Grey-Taguchi method to optimize the micro-drilling of PMMA polymer with multiple performance indices by taking machining parameters. The performance was evaluated by drill wear and surface roughness. The optimal combination was determined by using the grey relational grade, a performance index formed by combining the two performance characteristics.

M. K. A Mohd Ariffin *et al.* [6] reported an investigation to optimization of drilling cutting process of composite sandwich panel as testing material. Two type of drill bit HSS and carbide drill bit were selected and controlling parameters as drill bit material, cutting velocity, feed rate and hole diameter were analyzed using Design of Experiments. A holes were analyzed using Regression analysis technique to obtain the optimized range of cutting speeds. Minimum damage length was obtained for drill bit material.

Tsao *et al.* [7] predicted the thrust force and surface roughness in drilling of composite material using HSS drill using Taguchi method and the artificial neural network. The experimental results indicated that the feed rate and the drill diameter were the most significantly affecting the thrust force, while the feed rate and spindle speed contribute to the surface roughness.

S. Basavarajappa, G. Chandramohan, J. Paulo Davim. [8] studied the influence of cutting parameters on drilling characteristics of hybrid metal matrix composites (MMCs)—Al2219/15SiCp and Al2219/15SiCp–3Gr. The Composites were fabricated using stir casting method. Experiment results revealed that the dependent variables are greatly influenced by the feed rate rather than the speed for both the composites. The ceramic–graphite reinforced composite has better machinability than those reinforced with SiCp composites.

Paulina and Maria [9] has carried out surface roughness testing of a drilled hole wall. It was increases as drill temperature increases during drilling. Drill temperature tends to increase with the workload on the drill caused by the friction between the hole wall and the land or margin of the drill, regardless of drilling and material conditions. Therefore, a reduction in the workload caused by friction is effective for improving the quality of micro-drilled holes.

1.3. Taguchi Method

Dr. Genichi Taguchi (1924-2012) an electrical engineer developed the statical concept for quality improvement in era around the world war II. During 1940s the telephone systems of Japanese was in poor state. He worked for Nippon telegraph and telephone system to develop methods for enhancing the quality and reliability of the System. Many Japanese manufacture have used his approach for improving product and process quality with unprecedented success. The quality of Japanese automobile is attributable largely to wide spread application of Taguchi method.

Traditional experimental design methods are very complicated and difficult to use. Additionally, these methods require a large number of experiments when the number of process parameters increases [8]. In order to minimize the number of tests required, Taguchi experimental design method, a powerful tool for designing high-quality system, was developed by Taguchi. This method uses a special design of orthogonal arrays (OA) to study the entire parameter space with small number of experiments only.

Taguchi recommends analyzing the mean response for each run in the inner array, and he also suggests analyzing variation using an appropriately chosen signal-to-noise ratio (S/N). The S/N ratio measures the sensitivity of the quality characteristic being investigated in a controlled manner to those external influencing factors (noise factors) not under control.

There are 3 Signal-to-Noise ratios of common interest for optimization of Static Problems [3];

(I) SMALLER-THE-BETTER:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum\nolimits_{i=1}^{n} y^2\right)$$

e.g. minimum shrinkage in a cast iron cylinder.

(II) LARGER-THE-BETTER:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum\nolimits_{i=1}^{n} \frac{1}{y^2}\right)$$

e.g. maximum expected life of a component

(III) NOMINAL-THE-BEST:

$$\frac{S}{N} = -10\log\left(\frac{1}{n}\sum\nolimits_{i=1}^{n} \frac{\overline{y}}{s^2}\right)$$

e.g. dimension of a part consistent achieved with modest variance.

Where n is no of observation, y is observed data $\overline{y}$ is mean, s^2 is variance

The optimal level of the Drilling process parameters is the level with the nominal S/N value so criteria of nominal is better is taken.

Experimental Setup

Design of experiments : Design of experiment is scientifically setup of the different involved parameters in various combination to do particular operation but generally as the no. of factors increases the no combination also increase. It becomes difficult to try all possible combination as it consumes money time and effort .Therefore Taguchi based DOE design of experiment is designed using the OA orthogonal array.

Taguchi optimization procedure begins with selection of orthogonal array (OA) with distinct number of levels (L) defined for factor (l) such as cutting speed (v), feed rate (f), point angle(θ).

Minimum number of trials in the array is

N_a = $(L\text{-}1)F + 1$,

= (3-1)3+1

= 7=9

where F = number of factors = 3

therefore we take Orthogonal array of L_9, experiment set up is designed for three levels of Speed, Feed rate, Point angle the Orthogonal Array for 3 response factors with 3 level is formed and experiment is conducted according to OA (Table 2).

Table 1

Factors and levels

Factors	*Levels* 1	2	3
Spindle speed, N (rpm)	1500	2000	2500
Feed rate, *f*(mm/rev)	.05	.09	.13
Point angle, θ	118	126	134

Table 2

Levels *Trial no.*	*Speed* A	*Feed rate* B	*Point angle* C
1	1500	0.05	118
2	1500	0.09	126
3	1500	0.13	134
4	2000	0.05	126
5	2000	0.09	134
6	2000	0.13	118
7	2500	0.05	134
8	2500	0.09	118
9	2500	0.13	126

After the set up for experiment is designed experiment is conducted. Total nine no. of drilling operation was done with HSS tool drill bill 1.00 mm on steel sheet SS 403 10x10x 1.5 mm with three different tool point angle in CNC machine with designed parameters. and results were scanned through optical digital imaging microscope and measurement for diameter was done mean diameter of hole,

$$D_h = \frac{D_1 + D_2}{2}.$$

Table 3

Source	*Degree of freedom*	*Sum of squares*	*variance*	*F ratio*	*P value*	*Percentage Contri-bution*
A	2	1872.5	936.26	15.19	0.062	23.31 %
B	2	5911.9	2955.94	47.96	0.020	73.61 %
C	2	123.1	61.53	1	0.500	1.5 %
Error	2	123.1	61.64			1.5%
total	8	8030.8				100

Table 4

Trial no.	D_1	D_2	D_h	*MRR*
1	1.0895	1.0708	1.08015	58.875
2	1.1137	1.0859	1.0998	105.975
3	1.0539	1.0506	1.05225	153.075
4	1.0519	1.0803	1.0661	78.5
5	1.0611	1.0711	1.0661	141.3
6	1.0135	1.0221	1.0178	204.1
7	1.1274	1.1206	1.124	98.125
8	1.0973	1.0493	1.0733	176.625
9	1.0565	1.0973	1.0769	255.125

Material removal rate [2] is calculated as

$$\text{MRR} = \frac{\pi D_b^2 fN}{4}$$

Where is diameter of drill bit i.e. 1.00 mm *f* is feed rate in mm/rev, N is rpm of drill bit.

Analysis of output response: The output measured is now calculated for S/N ratio with criteria of nominal the better because diameter has to be uniform along with material rate for optimum drilling parameter. Statistical software Minitab 15 trial version is used for calculating S/N ratio (Table 5) and generating ANOVA Table (Table 3) and Response table (Table 6).

ANOVA is statistically based objective decision making tool for detecting any differences in the average performance of groups of item tested. ANOVA helps in formally testing the significance of all main factors and their interaction by comparing the mean factors and their interaction by comparing the mean square an estimated of experimental error at specific confidence levels.

Degree of freedom (DOF): Degree of freedom is defined as the number of comparison between design parameter that need to be made to determine which level is better specifically and specifically how much better it is

The **Percentage contribution P%** can be calculated as P% = SS_d/SS_T, where SS_d is sum of squared deviation, SS_T is total sum of squared deviations.

F-test tool named after R.A.Fisher is used to analyze design parameter have a significant effect on the quality characteristics. In the analysis, the F ratio is a ratio of the mean square error to the residual error and is used to determine the significance of a factor

The **P—value** reports the significance level (suitable and unsuitable) of factors .per cent (%) is defined as the significance rate of the process parameters on the metal removal rate MRR and hole diameter D_h

Analysis of response table gives better significance of the input parameter .average mean S/N ratio is found out for each factor at each level. Delta is the difference of maximum and minimum S/N ratio in each factor. And it gives idea about each factor how it is governing the overall output. Rank is given in decreasing order of delta.

Table 5

Trial no.	*Speed N*	*Feed f*	*Point θ*	*S/N ratio*
1	1	1	1	-2.69155
2	1	2	2	-2.83001
3	1	3	3	-2.89088
4	2	1	2	-2.77436
5	2	2	3	-2.87923
6	2	3	1	-2.92367
7	3	1	3	-2.81130
8	3	2	1	-2.90474
9	3	3	2	-2.93697

Table 6

Level	*Speed*	*Feed*	*Point angle*
1	-2.804	-2.917	-2.840
2	-2.859	-2.759	-2.847
3	-2.884	-2.871	-2.860
Delta	0.080	0.158	0.020
Rank	2	1	3

RESULT AND CONCLUSION

This study as discussed has used the Taguchi method for performance characteristics as Nominal is better and experiment were performed to L_9 OA. After the drilling process the drilled hole were measured and ANOVA response table, SNR values for each trail set up is calculated using the Mini tab ver. 15 Software. Optimum drilling parameters were selected as N_2 for speed = 2000 rpm, f_3 feed rate =.13 mm/rev and θ_2 Tool point angle = 126°. In percentage contribution feed rate has about 73.61%, spindle speed has 23.31% and tool point angle has 1.5% influence on the optimum diameter and material removal rate combinely. After analysis of the plot (Fig. 1) for MRR means Vs three process parameter it is concluded that as spindle speed and feed rate increases material removal rate increases along with nominal diameter but tool point angle has not significant effect and remains constant in this process.

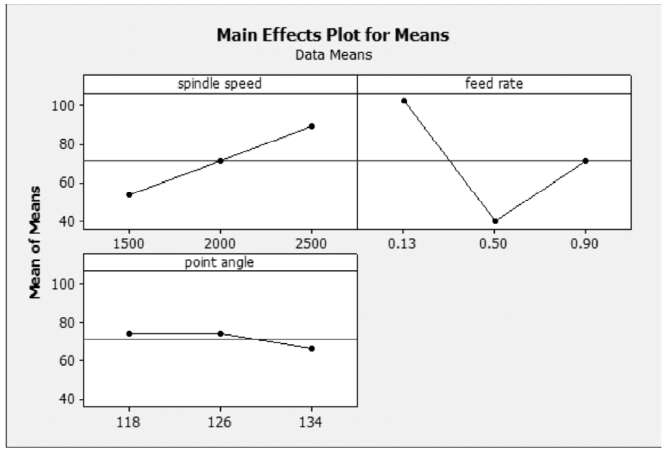

Figure 1

REFERENCES

[1] Dong-Woo Kim, Myeong-Woo Cho, Tae-Il Seo and Eung-Sug Lee, Application of Design of Experiment Method for Thrust Force Minimization in Step-feed Micro Drilling, Sensors 2008, 8, 211-221.

[2] Azlan Abdul Rahman, Azuddin Mamat and Abdullah Wagiman, Effect of Machining Parameters on Hole Quality of Micro Drilling for Brass, *Modern Applied Science*, **3**(5), 2009.

[3] Hyun-Ho Kim, Siyon Chung, Seung-Chul Kim, Condition Monitoring of Micro-drilling Processes on Glass by using Machine Vision, Department of Mechanical Design and Production Engineering, Hanyang University, SungdongGu, Seoul 133-791, Korea.

[4] R. Vimal Sam Singh, B. Latha, and V. S. Senthilkumar, Modelling and Analysis of Thrust Force and Torque in Drilling GFRP Composites by Multifaceted Drill using Fuzzy Logic, *International Journal of Recent Trends in Engineering*, **1**(5), 2009.

[5] Yu Teng Liang *et al.*, (2009), Investigation into Micro Machining Cutting Parameters of PMMA Polymer Material Using Taguchi's Method, 2009, Key Engineering Materials, 419-420, 341.

[6] M. K. A Mohd Ariffin, M. I. Mohd Ali, S. M. Sapuan and N. Ismail, An Optimise Drilling Process for an Aircraft Composite Structure using Design of Experiments, Scientific Research and Essay, **4**(10), 1109-1116, 2009.

[7] C.C. Tsao, H. Hocheng, Evaluation of Thrust Force and Surface Roughness in Drilling Composite Material using Taguchi Analysis and Neural Network. Department of

Automatic Engineering, Ta Hua Institute of Technology, Hsinchu 30740, Taiwan, ROC, Department of Power Mechanical Engineering, National Tsing Hua University, Hsinchu 30013, Taiwan, ROC.

[8] S. Basavarajappa, G. Chandramohan, J. Paulo Davim, Some Studies on Drilling of Hybrid Metal Matrix Composites based on Taguchi Techniques, Department of Mechanical Engineering, University BDT College of Engineering, Davanagere-577004, India, Department of Mechanical Engineering, PSG College of Technology, Coimbatore-641004, India, Department of Mechanical Engineering, University of Aveiro, Campus Santiago, 3810-193Aveiro, Portugal.

[9] Paulina and Maria (2008) Evaluation of Cutting Forces in Orthogonal Cutting of Composites Nonconventional Technologies Review – no. 3 / 2008.

[10] Frederico Ozanan Neves, and Gregório Christo Nocelli in 2011. Evaluation of Hole Quality for Hardened Steel in High Speed Drilling using Different Cooling System. Hindawi pub. 36.307-352.

[11] Jinan A. Abdulnabi, Thaier A. Tawfiq,Anwaar (2008), Pricise Hole Drilling in PMMA using 1064 nm diode laser cnc machine. Hindawi pub 10.1155/2011/137407.

[12] Tanwar, Gupta (2006), Dielectric Relaxation of PMMA in dilute Solutions IJPAP 44, 548-533.