Available online at www.sciencedirect.com

ScienceDirect

Procedia Technology

ELSEVIER

Procedia Technology 25 (2016) 1106 – 1113

Global Colloquium in Recent Advancement and Effectual Researches in Engineering, Science and Technology (RAEREST 2016)

Optimization of Cutting Parameters in Drilling Of AISI 304 Stainless Steel Using Taguchi and ANOVA

M. Balaji[a*], B.S.N. Murthy[b], N. Mohan Rao[c]

[a] *Department of Mechanical Engineering, V R Siddhartha Engineering College, Vijayawada, A.P., INDIA,*
[b] *Department of Mechanical Engineering, GIT, GITAM University, AP, INDIA and*
[c] *Department of Mechanical Engineering, University College of engineering, Vizianagaram, JNTUK, AP, INDIA.*
**Corresponding author: M Balaji, balajim315@gmail.com, Phone No: +91 8885544777*

Abstract

The present work deals with the effect of cutting parameters namely cutting speed, feed rate and helix angle on the tool life. The experiments were performed on drilling of AISI304 steel with carbide drill bits. Design of experiments was prepared according to Taguchi orthogonal array of L8 and experiments were performed with two levels of the cutting parameters. The effects of cutting parameters were analyzed by evaluating the amplitude of drill bit vibration and surface roughness. A Laser Doppler Vibrometer (LDV) was used for online data acquisition of drillbit vibration and a high-speed Fast Fourier Transform analyzer is used to process the acousto optic emission (AOE) signals. Taguchi and Analysis of Variance methods were used to identify significant cutting parameters affecting the drill bit vibrations and surface roughness. From the experimental results vibration of drill bit is found to be increased with the progression of the tool wear. Optimum levels of cutting parameters for surface roughness are obtained as 25 degrees of helix angle, 12mm/min of feed rate and 800rpm spindle speed. Optimum levels of cutting parameters for acceleration of vibration are obtained as 25 degrees of helix angle, 10mm/min of feed rate and 600rpm spindle speed.

Peer-review under responsibility of the organizing committee of RAEREST 2016

Keywords: Tool wear; Acousto-optic emission; ANOVA; Taguchi; Laser Doppler Vibrometer.

1. Introduction

Surface roughness is an indicator of surface quality which is prime requirement of customer for machined

Peer-review under responsibility of the organizing committee of RAEREST 2016
doi:10.1016/j.protcy.2016.08.217

parts. Good surface quality is essential for manufacturers to improve functional and technical quality of any product. Surface quality is the commonly used criteria in determination of milled steel quality. Etory Madrilles Arruda et.al. [1] conducted milling experiments on AISI P20 work pieces with 6mm dia solid carbide tools at different feed rate, radial depth of cut and contact angle. From the experimental results, the feed rate was found to be most significant parameter on surface quality. Kadivar et al. [2] investigated the effect of ultrasonic vibration on drilling force, reduction of burr size and surface roughness with two vibration systems. These two systems are used to vibrate work piece as well as tool. A 5mm diameter TiN coated HSS drills are used in drilling of Al/SiCp metal matrix composites. They concluded that the use of ultrasonic vibration reduces the burr height, drilling force and surface finish when compared to conventional drilling. In drilling process, dimensional accuracy, cylindricity and surface quality are the critical characteristics which determine the quality of drilled hole. Because, during assembly process burr is considered to be a negative outcome. Ultrasonic vibration is one of the methods used to reduce or remove burrs from drilled hole in order to improve surface finish.

Turgay Kıvak et al. [3] conducted experiments to assess the machinability of steel with PVD and CVD coated carbide inserts under dry milling. By using ANOVA effect of machining parameters on surface roughness and flank wear was determined. From the experiments, it is found that feed rate is the most important factor affecting surface roughness and cutting speed was affecting flankwear. K.Venkata Rao et al. [4] studied the surface roughness, tool wear and vibration of work piece in boring with cemented carbide inserts. A non contact type Vibrometer (LDV) is used to get the vibration data of work piece and an FFT is used to process Acousto optic signals. By considering nose radius, volume of material removed, feed and cutting speed a back propagation algorithm was developed for checking multi layer perception.

LDV's are being used to observe high frequency vibrations during machining process. In this present work, a Laser Doppler Vibrometer was used to observe vibration of work piece and FFT used to transform the AOE signals in to time domine. Nakagawa et al. [5] used Laser Doppler Vibrometer to observe the chattering behaviors of the end-mill shank. Chatter vibrations at high cutting speed were measured accurately by LDV. Balla et al. [6] also used LDV to observe vibration of work piece and used a Fast Fourier Transform preprocessor for generating features from online AOE signals to develop a database for appropriate decisions

According to Chang [7], the surface roughness and tool wear are strongly affected by the vibration amplitude and frequency. Two different helix angles were taken in the present work to evaluate effects of vibrations on tool life and surface roughness. Luke et al. [8] pointed that two types of vibrations may occur in machining, such as forced vibration and self excited vibration, Forced vibration is associated with bad gear drives, unbalanced machine-tool components, misalignment, or motors and pumps, etc. Self-excited vibration is occurring due to chatter which is caused by the interaction of the chip removal process and the structure of the machine tool and results in disturbances in the cutting zone. Chatter always indicates defects in the self-excited vibration.

Lin and Chang [9] shown that vibrations have strong correlation with surface roughness. Accordingly, various features of vibration signals have been chosen to estimate surface quality. In the present work, effects of vibration signals on tool wear and surface quality were studied. Salgado et al. [9] studied the cutting parameters, feed rate, spindle speed, depth of cut, tool nose radius, nose angle and vibration data which are the input information for evaluation of tool life. Two levels of spindle speed, feed rate and helix angle were taken in this work to evaluate tool life. Marimuthu and Cahndrasekaran [10] stated that, optimization of cutting parameter is required for good quality of products and production rate.

2. Methodology

Taguchi and analysis of variance methods were used to analyze the experimental data to find out affect and contribution of cutting parameters. Two characteristics viz Acceleration of drill bit vibration and surface roughness were taken in this work for evaluation of tool life

2.1. Taguchi

Taguchi method is being widely used in all the applications as a powerful tool to analyze the cutting parameters. This was successfully used in the unconventional machining process by Lin et al. [11]. A specially designed orthogonal array of Taguchi was used in this work to investigate the effects of the entire machining parameters through the small number of experiments and it takes less time for the experimental investigations.

2.1.1 Signal-to-Noise (S/N) ratio characteristics

Yang and Tarng [12] have used the Taguchi method for optimization of cutting parameters in turning. The Taguchi method uses *S/N* ratio to measure the variations of experimental design. The word signal says the desirable value and the word noise says the undesirable value. S/N ratios were calculated for surface roughness and amplitude of drill bit vibration using smaller is the best characteristic.

Smaller is the best

$$S/N = -10\log\left((I/n)\left(\sum y^2\right)\right) \quad (1)$$

Where, $\hat{y}$ is average of observed data y, s_y^2 is variance of y, and n is number of observations

2.2 Selection of cutting parameters

Nalbant et al. [13] also used Taguchi technique to find out the significant cutting parameter to minimize the surface roughness in turning of steels. In this work, the cutting parameters like helix angle (HA), rotational cutting speed (SS) and feed rate (F) were selected as control factors with two levels. An appropriate orthogonal array was selected to determine the optimal cutting parameters and to analyze the effects of these parameters.

Twist drills without chip breaker have significant effect on torque, cutting force, drill life and surface roughness. Continuous chip in the drilling results in surface roughness and tool wear on the flank [15]. In this study, helix angle was found to be significant on the surface roughness. In addition to that, interaction of helix angle with feed rate and spindle speed and interaction of spindle speed and feed rate were also found to be significant.

3. Materials and experimentation

Drilling experiments were performed on AISI 304 steel, the chemical composition of which is shown in the Table.1. It can be used for manufacturing sinks and splash backs, saucepans, springs, nuts, bolts and screws, medical implants etc. AISI 304 stainless steel is austenitic grade. This property has resulted in 304 being the dominant grade used in applications like marine equipment, fasteners, nuclear vessels and oil well filter screens.

Table 1. Chemical composition of AISI 304

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Fe
%	0.081	0.368	1.74	0.018	0.019	19.04	7.93	1.24	Remaining

Physical Vapour Deposition (PVD) coated carbide twist drills with 10 mm diameter were used to drill holes in the work piece. Helix angle (H A-2 levels), feed rate (F R-2 levels) and spindle speed (S S-2 levels) were taken as drilling parameters (Table 2). According to design of experiments, 8 combinations of drilling parameters were designed and experiments performed in CNC machine (Table 3). Thickness of work piece considered in this work was 35mm.

Table 2. Drilling parameters and their levels

Factors	units	Level 1	Level 2
Helix Angle (H A)	degrees	25°	30°
Feed Rate (F R)	mm/min	10	12
Spindle speed (S S)	rpm	600	800

Fig.1 Experimental Setup for drilling

The following sequential procedure was used to carry out the experiments under dry condition.
i. Each trial was started with a new drill bit with one test condition (trial) and 4 holes were drilled in each test condition. Experimental set up is shown in Figure 1.
ii. LDV was placed in front of the machine and the laser beam was focused on rotating drill bit to measure vibration signals.
iii. After drilling of each hole, work piece and drill bit were removed and surface roughness (Ra) was measured using Talysurf.

The above steps were repeated four times in each test condition to make four holes. The surface roughness (Ra) and acceleration of drill vibration (Acc.) obtained from 8 trials were shown in the Table 3 and Table 6 respectively.

4. Analysis of surface roughness

S/N ratios were calculated with Taguchi method for surface roughness (Ra) using smaller the better characteristic and S/N ratios are presented in Table 3.

Table 3: DOE and experimental results of surface roughness

Exp. No.	Design of Experiments			Surface roughness (μm)					
	H A	F	S S	R 1	R 2	R 3	R 4	MEAN	S/N Ratio
1	25	10	600	2.94	3.84	3.89	6.07	4.1850	-12.7512
2	25	10	800	2.51	2.82	3.10	4.10	3.1325	-10.0724
3	25	12	600	2.51	2.82	3.10	4.10	3.1325	-10.0724
4	25	12	800	2.63	3.10	3.89	3.95	3.3925	-10.7245
5	30	10	600	4.42	5.20	6.11	6.33	5.5150	-14.9128
6	30	10	800	4.04	5.32	5.81	6.13	5.3250	-14.6224
7	30	12	600	4.01	4.87	5.74	6.53	5.2875	-14.6009
8	30	12	800	3.32	4.19	4.57	5.87	4.4875	-13.2181

4.1. Taguchi

The Taguchi analyzed the S/N ratio of surface roughness for a cutting parameter which has more effect on the roughness. Taguchi results show that the Helix angle has more influence on the surface roughness and shown with 1st rank in Table 4.

Table 4. Taguchi analysis

Level	H A	F	S S
1	-10.91	-13.09	-13.08
2	-14.34	-12.15	-12.16
Delta	3.43	0.94	0.92
Rank	1	2	3

4.2. ANOVA

In the ANOVA, at a confidence level of 95%, the experimental results and the Taguchi S/N ratios were evaluated as shown in Table 5. ANOVA also determined the contribution of individual cutting parameters on the surface roughness. According to the ANOVA for S/N ratio of surface roughness, the Helix angle is showing more contribution of 79.88%. Here the error was found as 7.65%.

Table 5. Analysis of Variance for Signal to Noise Ratios

Source	DF	SS	MS	F	P	% contribution
H A	1	24.439	24.439	10.43	0.019	79.88
F	1	1.689	1.689	0.72	0.152	5.52
S S	1	1.578	1.578	0.67	0.162	5.15
H A*F	1	0.000	0.000	0.00	0.296	0.00
H A*S S	1	0.001	0.001	0.00	0.286	0.00
F*S S	1	0.545	0.545	0.23	0.214	1.80
Error	1	2.343	2.343			7.65
Total	7	30.594				100

Distribution of S/N ratios to the levels of cutting parameters is shown in Figure 2. From Figure 6, the optimum levels of cutting parameters are obtained as 25 degrees of helix angle, 12mm/min of feed rate and 800rpm spindle speed.

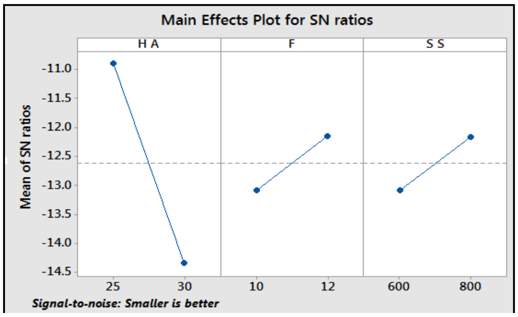

Fig 2. Main effects plot for Signal to Noise for surface roughness

5 Analysis of work piece vibrations for tool life

S/N ratios were calculated with Taguchi method for acceleration of drill vibration velocity using smaller the better characteristic and presented in Table 6.

Table 6: DOE and experimental results of acceleration of drill vibration velocity

Exp. No.	Design of Experiments			Acc. (m/sec^2)					
	H A	F	S S	R 1	R 2	R 3	R 4	MEAN1	S/N Ratio
1	25	10	600	0.1257	0.1345	0.1324	0.1218	0.12860	17.8084
2	25	10	800	0.1569	0.1510	0.1600	0.1468	0.15367	16.2631
3	25	12	600	0.1569	0.1510	0.1600	0.1468	0.15367	16.2631
4	25	12	800	0.1797	0.1918	0.2064	0.1719	0.18745	14.5213
5	30	10	600	0.2086	0.2414	0.1677	0.2235	0.21030	13.4712
6	30	10	800	0.1448	0.1556	0.1504	0.1542	0.15125	16.4028
7	30	12	600	0.1448	0.1556	0.1504	0.1542	0.15125	16.4028
8	30	12	800	0.2256	0.2371	0.3930	0.2767	0.28310	10.7298

5.1. Taguchi

For better tool life and surface quality of machined surface, acceleration of drill vibration should be less. Hence in this analysis smaller is better mode was selected. According to Taguchi results the Helix angle has more influence on the amplitude and shown with 1st rank in Table 7.

Table 7: Taguchi analysis

Level	H A	F	S S
1	16.21	15.99	15.99
2	14.25	14.48	14.48
Delta	1.96	1.51	1.51
Rank	1	2.5	2.5

5.2. ANOVA

In the ANOVA, at a confidence level of 95%, the S/N ratios were evaluated as shown in Table 8. ANOVA also determined the contribution of individual cutting parameters on the amplitude of work piece vibration. According to the ANOVA for S/N ratio of experimental results, the Helix angle is showing more contribution of 50.02%. Here the error was found as 10.85%.

Table 8: Analysis of Variance for Signal to Noise Ratios

Source	DF	SS	MS	F	P	% contribution
H A	1	17.701	7.701	0.87	0.042	50.02
F	1	4.543	4.543	0.51	0.204	12.85
S S	1	4.543	4.543	0.51	0.204	12.85
H A*F	1	0.037	0.037	0.00	0.359	0.1
H A*S S	1	0.037	0.037	0.00	0.359	0.1
F*S S	1	4.682	9.682	1.10	0.485	13.23
Error	1	3.837	8.837			10.85
Total	7	35.381				100

Distribution of S/N ratios to the levels of cutting parameters is shown in Figure 2. From Figure 6, the optimum levels of cutting parameters are obtained as 25 degrees of helix angle, 10mm/min of feed rate and 600rpm spindle speed.

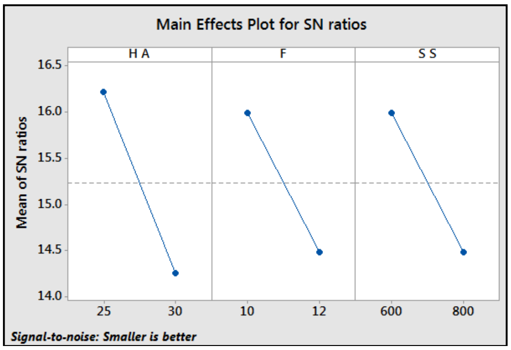

Fig 3. Main effects of plot for S/N ratios for work piece vibration

5. Conclusions

In this work, eight experiments (trials) were conducted with two levels of cutting parameters on AISI 304 steel. A noncontact monitoring system was used with laser Doppler vibrometer to observe vibration of drill bit during machining. Tool life was evaluated by analyzing surface roughness and acceleration drill bit vibration velocity with the help of Taguchi and ANOVA analysis.

The following points can be concluded from this work.

1. Vibration of drill bit is found to be increased along with the progression of the tool wear.
2. Helix angle is found to be significant on surface roughness followed by acceleration of drill vibration velocity with contribution of 78.22% and 50.02% respectively.
3. Optimum levels of cutting parameters for surface roughness are obtained as 25 degrees of helix angle, 12mm/min of feed rate and 800rpm spindle speed. Optimum levels of cutting parameters for acceleration of vibration are obtained as 25 degrees of helix angle, 10mm/min of feed rate and 600rpm spindle speed.

6. References

[1] Etory Madrilles Arruda, Lincoln Cardoso Brandão , Sérgio Luiz Moni Ribeiro Filho, Juliano Aparecido de Oliveira, Integrated optimization using mixture design to confirm the finishing of AISI P20 using different cutting strategies and ball nose end mills, Measurement 47 (2014) 54–63.
[2] M.A. Kadivar a,n , J. Akbari b,c,1 , R. Yousefi d,2 , A. Rahi a,3 , M.Ghahramani Nick, Investigating the effects of vibration method on ultrasonic-assisted drilling of Al/SiCp metal matrix composites, Robotics and Computer-Integrated Manufacturing 30 (2014) 344–350
[3] Turgay Kıvak, Optimization of surface roughness and flank wear using the Taguchi method in milling of Hadfield steel with PVD and CVD coated inserts, Measurement 50 (2014) 19–28.
[4]K. Venkata Rao , B.S.N. Murthy , N. Mohan Rao, Prediction of cutting tool wear, surface roughness and vibration of work piece in boring of AISI 316 steel with artificial neural network, Measurement 51 (2014) 63–70.
[5] H. Nakagawa, Y. Kurita, K. Ogawa, Y. Sugiyama, H. Hasegawa, Experimental analysis of chatter vibration in end-milling using laser Doppler vibrometers, International Journal of Automation Technology 2 (6) (2008) 431–438.
[6] Balla Srinivasa Prasad, M.M.M. Sarcar, B. Satish Ben, Development of a system for monitoring tool condition using acousto-optic emission signal in face turning—an experimental approach, International Journal of Advanced Manufacturing Technology 51 (2010) 57–67
[7] Chang FX, An experimental study of the impact of turning parameters on surface roughness, in: Proceedings of

the Industrial Engineering Research Conference, Paper No. 2036, GA, 2001.
[8] Luke.H. Huang, Joseph.C. Chen, A multiple regression model to predict in-process surface roughness in turning operation via accelerometer, Journal of Industrial Technology 17 (2) (2001) 2–7.
[9] D.R. Salgado, F.J. Alonso, I. Cambero, A Marcelo, In-process surface roughness prediction system using cutting vibrations in turning, International Journal of Advanced Manufacturing Technology 43 (2009) 40–51.
[10] P. Marimuthu, K. Chandrasekaran, Experimental study on stainless steel for optimal setting of machining parameters using Taguchi and neural network, Arpn Journal Of Engineering and Applied Sciences 6 (10) (2011) 119–127.
[11] Y.C. Lin, Y.F. Chen, D.A. Wang, H.S. Lee, Optimization of machining parameters in magnetic force assisted EDM based on Taguchi method, Journal of Materials Processing Technology 209 (7) (2009) 3374–3383.
[12] W.H. Yang, Y.S. Tarng, Design optimization of cutting parameters for turning operation based on Taguchi method, Journal of Material Process 84 (1998) 127–129.
[13] M. Nalbant, H. Gokkaya, G. Sur, Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning, Materials and Design. 28 (4) (2007) 1379–1385
[14] Bala Murugan Gopalsamy, Biswanth Mondal, Sukamal Ghosh, Taguchi method and ANOVA: An approach for process parameters optimization of hard machining while machining hardened steel, Journal of Scientific and Industrial Research 68 (2009) 686–695.
[15] Sushanta K. Sahu, O. Burak Ozdoganlar, Richard E. DeVor, Shiv G. Kapoor, Effect of groove-type chip breakers on twist drill performance, International Journal of Machine Tools and Manufacture 2003; 43 (6): 617–627.