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Roundness Error in Deep Hole Drilling using Twist Drills and Cold Mold Steel 718

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Abstract

Applications: Deep hole drilling is one of the machining processes which currently has been applied in the manufacturing area. The sophistication in some area such as aerospace, automotive, wind energy and nuclear power encourage the application of deep hole drilling. **Objectives:** In this study the effect of machining parameters on the roundness error during the drilling multiple deep holes of steel alloy using HSS Co5 DH100 straight shank twist drills for deep hole drilling of cold mold steel 718 towards the value of roundness error was investigated. **Method:** Drilling tests were carried out using a CNC milling machine under three different levels of minimum quantity lubricant (20, 30, 40 ml/hour) by drilling three different levels of depth of holes (65, 70, 75 mm), three different levels of spindle speeds (700, 800, 900 rpm) and three different levels of feed rates (50, 60, 70 mm/min). **Findings:** It was observed that the minimum value of roundness error obtained when using DoE approach and regression model is when cutting speed (V) is 700 rpm, minimum quantity lubricant (l) is 40 ml/hr and feed rate (f) equals 50 mm/min, depth of hole (d) is 65 mm. ANOVA analysis also proves that the combination of machining parameters obtained is significantly to the roundness error value that results in the roundness error minimum value and F statistic also showed that the model is important at the significance level of 95%.

Keywords: Deep Hole Drilling, Design of Experiment (DoE), Machining, Minimum Quantity Lubricant (MQL), Roundness Error, Twist Drills

1. Introduction

Deep hole drilling is assumed as one of the machining processes that currently attracted the attention of manufacturers to be applied in the manufacturing area. Deep hole drilling has the capability to produce quality surface finish and straightness compared to the traditional drilling when the ratio of hole-depth to hole-diameter exceeds ten[1]. In other word, deep hole drilling refers to the machining process which the hole depth to diameter ratio exceeds 10[2].

The advent of new requirements and constraints in several areas such as aerospace, automotive, wind energy and nuclear power encourage the application of deep hole drilling[3]. This type of technology is still slightly used compared to turning, milling and grinding. There are a lot of deep-hole manufacturing parts such as the cooler intersection holes, screw boot holes of steam turbine and slanted wall holes in aero-spacecraft pressures regulator[4]. Mostly deep hole drilling process involved in the production of manufacturing parts that involves power and energy. As a result, manufacturing process of these type of products will affect the quality of the product.

However, how to estimate the problems of the drilling process efficiently and accurately still remains unresolved due to the diversity of machining conditions, the randomness of drilling rotational states and complexity of drilling mechanism[4]. Many issues related to deep hole drilling such as the increasing of depth to diameter ratio, encouraging the tool susceptible to vibration, producing chatter which result in degenerated the quality of drilled hole from the aspect of roundness, cylindricity,

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straightness and surface finish of the hole. Therefore, various machining conditions must be adjusted for the high quality hole. These machining conditions included the cutting speed, feed rate, type of material bit, type of cutting fluid, depth of hole, type of cutting environment and so on were investigated[2]. Harun et al.[5] conducted a study in deep hole drilling to analyze cutting force and vibrations using deep twist drills which are involved cutting speeds, feed rate and depth of cut as the machining parameters. The three-axis data of vibrations and force sensors have been used to measure the effects of tool condition during cutting operations. Then the results have been analyzed in time and frequency domain.

Among other issues arise in manufacturing is the use of Minimum Quantity Lubricant (MQL) where most manufacturing more likely use dry machining compared to the use of MQL. Unknowingly actually dry machining application increases energy consumption and production cost. The MQL has an ability to give the cooling effect along the drilling process as the drilling process generates a high thermal load which leads to the damage to the work piece. Biermann et al.[6] do a research in deep hole drilling by applying MQL to obtain a reliable chip removal compared using dry machining which is not attainable. The result shows that the MQL reduced the heat input into the work piece significantly which was related to the higher heat removal by the chips and generally decreased energy consumption of the cutting process.

It can be seen that the roundness error is affected by a few factors such as cutting speed, feed rate, cutting tool geometry, the microstructure of the work piece and the stiffness of the machine tool[7]. However, these machining parameters can be optimized using several approaches and models such as DoE approach and regression models. Therefore, most of the researchers have been concentrated on a suitable way to minimize the roundness error value[8–10].

Hence the development of research on the deep hole drilling process could help to improve the reliability of cutting tools, understand physically the cutting process and the appropriate selection of optimal machining parameters. The objective of this research is to investigate the effects of using HSS Co5 DH100 Straight Shank Twist Drills and the machining parameters on roundness error and to determine the optimal machining parameters using the DoE and regression model in deep hole drilling of cold mold steel 718.

2. Experimental Setup

The experiments were conducted using a CNC milling machine. There are various other machines that are utilized throughout the conducted experiment as noted in Table 1. The material used for work piece in the experiment was steel alloy as shown in Figure 1.

Figure 1. Work piece.

The tools used were HSS Co5 DH100 straight shank twist drills. The characteristics of tools tested are listed in Table 2. These geometric features of tools are recommended in deep-hole drilling[11]. HSS drill is

Table 1. Machine and specifications

Machine	Specification	Application
Surface Grinding Machine	OKAMOTO Model 63DX ACC	Use for clean the workpiece
CNC Milling Machine	MahoDeckel Model MH500E Controller Philips	Use for deep hole drilling process
CNC Wire Cut machine	Sodick Model AQ537L Controller sodick LN1W	Use for cut the workpiece
Coordinate Measuring Machine	Zeiss Model Contura G2	Use for measure the machining performance

superior compared to the older high carbon steel and has a property which is faster in drilling. Besides, HSS has high hardness and abrasion resistance. This type of HSS drill can be applied for drilling deep holes in non-alloy steels, alloy steels, grey cast iron, malleable cast iron, special aluminum or magnesium alloys. The example of HSS drills uses in this experiment is presented in Figure 2.

Figure 2. HSS drills.

Table 2. Characteristics of HSS drill used

Characteristic	
Standard	DIN 1896/1
Tool material	Cobalts 5% HSS is used in the tool material
Helix angle	38°
Tolerance of the tool diameter	h8
Point angle	130°
Art. -Nr. EDP No.	DL600050
Drill diameter, d_1	5 mm
Overall length, l_1	195 mm
Flute length, l_2	135 mm

The machining parameters are the control parameters which are taken in the experimentation. The changes value of machining parameters will determine the outcome of experimentations. The machining parameters used in these experiments include spindle speed, the holes' depth, MQL and feed rate are presented in Table 3 presents the machining parameters that were used in this experiment.

Table 3. Machining parameters and constraints

Machining parameter	Level 1	Level 2	Level 3
Spindle speed, V (rpm)	700	800	900
Feed rate, f (mm/min)	50	60	70
Depth of hole, d (mm)	65	70	75
Minimum quantity lubricant, l (ml/hr)	20	30	40

The MQL used in this experiment is palm oil. The capacity of high unsaturated fatty acids in palm oil enables high strength films responding well to the surface of the work piece and work well as a good lubricant at the same time reduce tool wear and friction against the work piece to ensure a good quality product[12]. The characteristic of palm oil used is indicated in Table 4.

Table 4. Characteristics of palm oil

Characteristic	
Density (g/cm^3)	0.91
Viscosity at 40°c (mm^2/s)	40
Viscosity index	190

3. Experimental Procedure

The experiment was basically designed using Design of Experiment (DoE) that has been arranged by using Minitab17 software as an introductory experiment which was considered by applying the design of full factorial two levels with four center point. DoE is one of the powerful statistical analysis techniques which are applied for modelling and analyzing statistical and engineering problems for developing, optimizing and improving various manufacturing process[2]. There are twenty tests conducted based on DoE as shown in Figure 3.

Results for: Worksheet 2

Full Factorial Design

```
Factors:   4  Base Design:        4, 16
Runs:     20  Replicates:             1
Blocks:    1  Center pts (total):     4

All terms are free from aliasing.


Design Table (randomized)

Run  A  B  C  D
  1  -  -  -  -
  2  +  -  +  +
  3  +  -  -  -
  4  -  +  +  -
  5  +  +  +  -
  6  0  0  0  0
  7  -  +  -  +
  8  -  -  +  -
  9  0  0  0  0
 10  +  +  -  -
 11  +  -  +  -
 12  +  +  +  +
 13  +  +  -  +
 14  -  +  -  -
 15  +  -  -  +
 16  0  0  0  0
 17  -  +  +  +
 18  -  -  -  +
 19  -  -  +  +
 20  0  0  0  0
```

Figure 3. Design of Experiment (DoE).

The next step is setting up the work piece, tool and MQL system as depicted in Figure 4. All the experiments were done based on the DoE. Each experiment was performed using new DH100CO5HSS straight shank twist drills. Thus, this experiment involves twenty new twist drills are used. This is to ensure the identification of the consequence of verifying optimum machining parameters for a minimum roundness error and also machining parameters on roundness error. The roundness error value in this experiment has been measured using a Coordinate Measuring Machine (CMM).

Figure 4. Installed work piece, tool and MQL.

4. Results and Discussion

The roundness error values of the holes drilled for deep hole drilling related to machining parameters were evaluated in this experiment. The roundness error produced for each experiment is measured by using Coordinate Measuring Machine (CMM). Figure 5 shows the holes drilled in deep hole drilling process with 20 holes are drilled in the work piece.

Figure 5. Holes drilled in the work piece.

The experimental roundness error results for drilling of deep hole are presented in Table 5. The roundness error minimum value is 0.0144 mm. The parameters of optimal machining are 700 rpm for cutting speed (*V*), 65 mm for deep of hole (*d*), 50 mm/min for feed rate (*f*) and 40 l/hr for minimum quantity lubricant (*l*). The results indicate that the minimum roundness error obtained at hole 6.

Table 5. Result of experiments for roundness error

	Spindle speed (*V*)	Feed rate (*f*)	Depth of hole (*d*)	MQL (*l*)	Roundness Error
Hole 1	700	50	65	20	0.0194
Hole 2	700	70	65	20	0.0298
Hole 3	700	50	75	20	0.0627
Hole 4	700	70	75	20	0.0440
Hole 5	800	60	70	30	0.0814
Hole 6	700	50	65	40	0.0144
Hole 7	700	70	65	40	0.0223
Hole 8	700	50	75	40	0.0653
Hole 9	700	70	75	40	0.0416
Hole 10	800	60	70	30	0.0534
Hole 11	900	50	65	20	0.0904
Hole 12	900	70	65	20	0.0747
Hole 13	900	50	75	20	0.0760
Hole 14	900	70	75	20	0.0565
Hole 15	800	60	70	30	0.0351
Hole 16	900	50	65	40	0.0478
Hole 17	900	70	65	40	0.0395
Hole 18	900	50	75	40	0.0560
Hole 19	900	70	75	40	0.0407
Hole 20	800	60	70	30	0.0288

The relative effect of the different factors can be obtained by the decomposition of variance which is called an analysis of variance (ANOVA). ANOVA is a statistical analysis which purposely used to identify the factors which significantly affecting the performance measures[13]. To determine the optimal combination of the machining parameters, the relative effect of the machining parameters with respect to roundness error was investigated by using ANOVA. Table 6 shows that the results of ANOVA analysis that was performed with a significance level of α = 0.05. The spindle speed, feed rate, depth of cut and MQL have significant contributions in roundness error model since these P-values are less than the significance level α = 0.05. It means that the model is considered to be statistically significant.

Table 6. Analysis of Variance (ANOVA)

Source	DF	SS	MS	F	P
Regression	4	0.0041736	0.0010434	3.44	0.035
Residual error	15	0.0045513	0.0003034		
Total	**19**	**0.0087249**			

Additional analysis applied is F statistic. The F statistic is a value obtain from an ANOVA test or a regression analysis to find out if the means between two populations are significantly different. The F test will determine if a group of variables are jointly significant. The large F-value indicates that most of the variation in the response can be explained by the regression model equation. The F-value obtained from this experiment is 3.44 which is greater than F-tabulated$_{4,\ 15}$ = 3.05 indicates that the model is significant at the confidence level of 95%. The regression analysis was employed to derive the equations of the roundness error. The equation of roundness error is shown below as Equation 1.

$$Roundness\ error = -0.0787 + 0.000114V - 0.000518f + 0.0013d - 0.0007871 \qquad (1)$$

5. Conclusions

The combination of machining parameters and constraints for deep hole drilling of cold mold steel 718 with HSS Co5 DH100 straight shank twist drills using a CNC milling machine has been presented. The parameters of optimal machining are 700 rpm for cutting speed (V), 65 mm for deep of hole, 50 mm/min for feed rate (f), (d) and 40 ml/hr for minimum quantity lubricant (l) where the roundness error is 0.0144 mm at hole 6. The analysis using ANOVA and F statistic also have shown that the combination of machining parameters and the model is significant for minimizing the roundness error. The outcome of the experiment has helped optimizing machining parameters involved based on this case study that leads to minimize the value of the roundness error in deep hole drilling which is considered as a necessity in a determination of product quality.

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7. References

1. Kong L, Chin JH, Li Y, Lu Y, Li P. Targeted suppression of vibration in deep hole drilling using magneto-rheological fluid damper. Journal of Materials Processing Technology. 2014 Nov 30; 214(11):2617–26. Crossref
2. Aized T, Amjad M. Quality improvement of deep-hole drilling process of AISI D2. The International Journal of Advanced Manufacturing Technology. 2013 Dec 1; 69(9–12):2493–503. Crossref
3. Thil J, Haddag B, Nouari M, Barlier C, Papillon L. Experimental and analytical analyses of the cutting process in the deep hole drilling with BTA (Boring Trepanning Association) system. Mechanics and Industry. 2013; 14(6):413–29. Crossref
4. Kong LF, Li Y, Lu YJ, Zhao ZY, Hou XL. A nonlinear dynamic finite element analysis of drilling shaft including multispan auxiliary supports in deep-hole machining. Advances in Mechanical Engineering. 2013; 5. Crossref
5. Harun MH, Ghazali MF, Yusoff AR. Analysis of tri-axial force and vibration sensors for detection of failure criterion in deep twist drilling process. The International Journal of Advanced Manufacturing Technology. 2016:1.
6. Biermann D, Iovkov I. Investigations on the thermal work piece distortion in MQL deep hole drilling of an aluminium cast alloy. CIRP Annals-Manufacturing Technology. 2015 Dec 31; 64(1):85–8. Crossref
7. Çiçek A, Kıvak T, Samtaş G. Application of Taguchi method for surface roughness and roundness error in drilling of AISI 316 stainless steel. Strojniškivestnik-Journal of Mechanical Engineering. 2012 Mar 15; 58(3):165–74. Crossref

8. Çiçek A, Kıvak T, Ekici E. Optimization of drilling parameters using Taguchi technique and response surface methodology (RSM) in drilling of AISI 304 steel with cryogenically treated HSS drills. Journal of Intelligent Manufacturing. 2015 Apr 1; 26(2):295–305. Crossref
9. Najarian F, Noordin MY, Nor FM, Kurniawan D. Analysis of deep hole drilling in presence of electromagnetic field using Taguchi technique. ASME 2014 International Mechanical Engineering Congress and Exposition; 2014 Nov 14. p. V02BT02A060. Crossref
10. Priarone PC, Ruffa S, Bedolla JS, Settineri L. A DoE approach to hole quality evaluation in drilling of an electron beam melted titanium aluminide. Procedia CIRP. 2013 Dec 31; 8:481–6. Crossref
11. Heinemann R, Hinduja S. A new strategy for tool condition monitoring of small diameter twist drills in deep-hole drilling. International Journal of Machine Tools and Manufacture. 2012 Jan 31; 52(1):69–76. Crossref
12. Lawal SA, Choudhury IA, Nukman Y. A critical assessment of lubrication techniques in machining processes: a case for minimum quantity lubrication using vegetable oil-based lubricant. Journal of Cleaner Production. 2013 Feb 28; 41:210–21. Crossref
13. Yildiz AR. Hybrid Taguchi-differential evolution algorithm for optimization of multi-pass turning operations. Applied Soft Computing. 2013 Mar 31; 13(3):1433–9. Crossref