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Optimization of Machining Parameters for Minimization of Roundness Error in Deep Hole Drilling using Minimum Quantity Lubricant

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Abstract. This paper presents an experimental investigation of deep hole drilling using CNC milling machine. This experiment investigates the effect of machining parameters which are spindle speed, feed rate and depth of hole using minimum quantity lubricant on the roundness error. The experiment was designed using two level full factorial with four center point. Finally, the machining parameters were optimized in obtaining the minimum value of roundness error. The minimum value of roundness error for deep hole drilling is 0.0266 at the spindle speed is 800 rpm, feed rate is 60 mm/min, depth of hole is 70 mm and minimum quantity lubricant is 30ml/hr.

1 Introduction

The demands in industrial nowadays need for the application of machining process to produce a particular product compared to the use of manpower in the past. Therefore, various types of machines have been introduced so far. Prior conventional machining was applied as turning [1, 2], milling [3, 4] drilling [5, 6], grinding [7] and so on. By its desire to meet the needs and demands of the present time, non-conventional machining or modern machining was introduced as abrasive water jet (AWJ) [8, 9], electrochemical machining (ECM) [10, 11], electric beam machining (EBM) [12, 13] and etc. Each machining process applied is based on the products to be produced. Thus, for the production of deep holes, a particular machining process is needed namely deep hole drilling.

The difference between drilling and deep hole drilling is based on the concept of deep hole drilling itself. Deep hole drilling is defined by its depth to diameter ratio (D: d) where the ratio is greater than 10: 1. In other definition, deep hole machining means machining of holes deeper than ten times the diameter of the holes. Deep hole drilling can be applied to a wide range of materials from aluminium to the super-alloy.

However, in order to produce a high-quality product range of issues that may affect the quality of the product is noteworthy. Furthermore, deep hole drilling process is a new

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machining process was introduced and there is not much research being done to improve the quality of the resulting holes. Deep hole drilling process involves the production of a deep hole where any machining parameters and constraints during the machining process is carried out can affect the quality of the hole.

The importance of deep hole drilling can be seen in some areas such as in the area of aerospace [14], oil and gas [15], mold and die [16] and others where the quality of the hole resulting the effectiveness of the product. Therefore, it is necessary to study and run the experiments to identify the effect of machining parameters on hole quality.

For this purpose, the effect of different combinations of spindle speed, feed rate, depth of hole and MQL was examined. The optimum machining parameters were specified and the effect of cutting parameters on the roundness error was investigated.

2 Experimental Setup

The deep hole drilling experiments were carried out on a Maho Deckel Model MH500E CNC milling machine. The workpiece material used in the experiment was steel alloy (Fig. 1**)**. The tools use was twisted drills (Fig. 2)**.** There are four machining parameters involved in conducting this experiments which are spindle speed, feed rate, depth of holes and minimum quantity lubricant (MQL). The four machining parameters and constraints involved in this experiment are shown in Table 1 below.

Table 1. Machining parameters and constraints.

Machining parameters	**Constraints**
Spindle speed (*V*)	700-900 rpm
Feed rate (*f*)	50-70 mm/min
Depth of hole (*d*)	65-75 mm
Minimum quantity lubricant (*l*)	20-40 l/hr

Fig. 1. Workpiece.

Fig. 2. Twist Drill.

The machine needs to be setup such as installing a workpiece, tool and MQL system. In the preliminary experiment, design of experiment (DOE) has been made using Minitab 17 software. The experiment was designed using two level full factorial with four center point. There are twenty tests conducted based on DOE. All experiments were performed based on the DOE. Therefore, this experiment involves twenty experiments to identify the effect of machining parameters on roundness error while identifying the optimum machining parameters to produce a minimum roundness error. The output which is roundness error was measured by a coordinate measuring machine (CMM).

3 Results and discussion

The variation of the roundness error of the drilled holes in relation to machining parameters involved was analyzed in this research. The result of experiments for roundness error is shown in Table 2 as shown below.

The result for optimization of machining parameters of deep hole drilling for roundness error is 0.0266 mm. The optimal machining parameters are 800 rpm for cutting speed (*V*), 60 mm/min for feed rate (*f*), 70 mm for deep of hole (*d*) and 30 l/hr for minimum quantity lubricant (*l*). It was found that minimum roundness error obtained at hole 20.

The ANOVA has been used to obtain the relative effect of the different factors by the decomposition of variance. By using ANOVA, the relative effect of the machining parameters with respect to diameter error was investigated to determine the optimal combination of the machining parameters. The results of ANOVA for this experiment was generated by Design Expert 7.

Table 2. The result of experiments for roundness error.

	Spindle speed (*V*)	**Feed rate (*f*)**	**Depth of hole (*d*)**	**Minimum quality lubricant (*l*)**	**Roundness error**
Hole 1	700	50	65	20	0.0327
Hole 2	700	70	65	20	0.0400
Hole 3	700	50	75	20	0.0550
Hole 4	700	70	75	20	0.0563
Hole 5	800	60	70	30	0.0527
Hole 6	700	50	65	40	0.0565
Hole 7	700	70	65	40	0.0639
Hole 8	700	50	75	40	0.0545
Hole 9	700	70	75	40	0.0605
Hole 10	800	60	70	30	0.0678
Hole 11	900	50	65	20	0.0683
Hole 12	900	70	65	20	0.0668
Hole 13	900	50	75	20	0.0467
Hole 14	900	70	75	20	0.0625
Hole 15	800	60	70	30	0.0457
Hole 16	900	50	65	40	0.0340
Hole 17	900	70	65	40	0.0366
Hole 18	900	50	75	40	0.0502
Hole 19	900	70	75	40	0.0524
Hole 20	800	60	70	30	0.0266

In Table 3, the results indicate that all the parameters are not significant for roundness error value as the α value used in ANOVA is 0.05. If $p < 0.05$, it shows that the observed different within four machining parameters are significant. However, all the machining parameters have $p>0.05$ which refer to the insignificant. This situation could indicate that this effect was certainly masked by the action of uncontrolled factors. These results would lead us to believe that some machining parameters need for improving this process.

Table 3. ANOVA for roundness error.

ANOVA for selected factorial model						
Analysis of variance table [Partial sum of squares - Type III]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	0.002047044	4	0.000511761	0.37576955	0.8221	not significant
A-Spindle Speed	0.000607178	1	0.000607178	0.445831272	0.5152	
B-Feed Rate	2.90946E-05	1	2.90946E-05	0.021363237	0.8859	
C-Depth of Hole	9.95027E-05	1	9.95027E-05	0.07306162	0.7909	
D-MQL	0.001311268	1	0.001311268	0.962822072	0.3431	
Curvature	3.39506E-05	1	3.39506E-05	0.024928854	0.8768	not significant
Residual	0.019066614	14	0.001361901			
Lack of Fit	0.015154451	11	0.001377677	1.056457169	0.5485	not significant
Pure Error	0.003912163	3	0.001304054			
Cor Total	0.021147608	19				

4 Conclusion

The experiment was conducted under three machining parameters and minimum quantity lubricant have managed to find a minimum value of roundness error. The minimum value of roundness error is 0.0266 at the spindle speed is 800 rpm, feed rate is 60 mm/min, depth of hole is 70 mm and MQL is 30ml/hr. The validation for the results of the experiment was performed using ANOVA. However the results were exhibited by ANOVA showed that the machining parameters and MQL is not significant to the roundness error. Therefore, the enhancements to the experiment need to be done to produce a better result.

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