Investigation of Effect of CNC Milling Parameters on Cylindricity and Perpendicularity of Milled Circular Pockets Using CMM

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Investigation of Effect of CNC Milling Parameters on Cylindricity and Perpendicularity of Milled Circular Pockets Using CMM

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Abstract: CNC milling is widely used in the present manufacturing scenario to manufacture components with complex shapes and profiles with high geometrical accuracy. The main aim of the present work is to analyze the significance of milling parameters on cylindricity and perpendicularity of circular pockets in CNC milling operation while machining AISI 304H stainless steel. Spindle speed and feed rate have been considered as machining parameters. The experimentation plan is implemented under Taguchi's L9 orthogonal array. The performance characteristics such as cylindricity and perpendicularity of the circular pockets were also measured using CMM. Mathematical models are developed using response surface methodology (RSM) to develop relationship between the input parameters and output responses.

Keywords: CNC Milling, Cylindricity, Perpendicularity, Taguchi's L9 Orthogonal Array, Response Surface Methodology

1. Introduction

In conventional machining it is very difficult to control the quality of the responses. CNC machines function with the combination of machine tool as well as control mechanism. CNC controllers are capable of point-to-point control following complex algorithms during functioning of the machine. CNC controllers can control more the one axis. It can control up to five axes and sometimes even six axes. Pocket milling is an important application in the area of machining of mechanical parts like jigs, fixtures, dies and moulds. This type of machining carries a great importance in aerospace and shipyard industries and other product design sectors. Quality of a pocket depends on various parameters like spindle speed, feed rate and work material.

Sotiris and Andreas[1)] exhibit the relationships between the geometry of the shape and different machining conditions like type of cutter and machine tool used in order to obtain the optimized cost and lead time during pocket milling. The effect of cutting force on the accuracy of the measurands during pocket milling was observed by Law and Geddam[2)]. Islam et al.[3)] analyzed the effects of the cutting conditions and tool configurations viz. tool material, diameter, and geometry on the accuracy of drilled holes. Diameter in the horizontal plane was measured on CMM with eight points. Gologlu et al.[4)] investigated the effect of cutting parameters and cutting path strategies on surface roughness found in pocket milling during plastic mould manufacturing. Mitesh Gohil[5)] et al. conducted the drilling of glass fiber reinforced plastic composites. Spindle speed, feed rate, point angle of drill are the input parameters. The response parameters are surface roughness, torque and thrust force. Design of experiments is used to find the important individual and interactive factors that affect the responses. Taguchi method along with ANOVA was used for minimization of delaminating.

Rehaman et al.[6)] studied the effect of drilling parameter on MRR, surface roughness, dimensional accuracy and burr. Accuracy of drill diameter, feed rate and spindle speed increase the dimensional accuracy of drilled holes (Azalan Abdul Rehaman et al., 2009). Thirenpokar et al.[7)] performed optimization and modeling of Micro drilling Process parameters, using grey based Taguchi method. Experiments are designed based on Taguchi's L9 orthogonal array design. Micro drilling parameters are feed rate and cutting speed and the responses are torque, thrust force and machining time and local circularity error. Bharti et al.[8)] observed the influence of machining parameters on the geometry of the hole and MRR in the process. Using DOE and ANOVA the optimized result was obtained. Palanikumar et al.[9)] achieved the impact of spindle speed and feed on separating layers during drilling of GFRP composites. Two fluted twist drill and four fluted cutter were used to conduct the trials. When twist drill was used the effect input parameter found was 3.04% and 93.15% respectively. When four fluted cutter was used the results were 0.15% and 97.67%. Sheth et al.[10] found the effect of input parameters during drilling of mild steel to justify the accuracy of performance characteristics viz. cylindricity and perpendicularity [11-14].They observed that three most important parameters are speed, feed and depth of cut during manufacturing of nozzle check valve.

Literature survey exhibits that most of the problems regarding assembly of the machinery components occur from their inaccurate geometry. Many geometrical tolerances viz. cylindricity, circularity, perpendicularity and location are accountable for the above problems in case of generating holes[16-23].These geometric tolerances must be checked during initial stages of pocket milling to meet the exact requirement for the product assembled. The objective of this investigation is to obtain the optimum milling parameters of AISI 304H steel using high speed steel end mills.

2. Experimentation

The workpiece used is 100mm x100mm x12mm square plate made of AISI 304H austenitic stainless steel with solution annealed condition (Fig 1 and 2). It is having tensile strength of 530 MPa, elongation of 45% and hardness of 215 HB. Table 1 shows its chemical composition. The pocket milling operation was done by HSS tool. AISI 304 stainless steel finds its application in air craft fittings, aerospace components such as bushings, shafts, valves, special screws, cryogenic vessels and components for severe chemical environments.

Table 1. Chemical composition of AISI 304H steel used in the experiments (%)

Composition	C	Si	Mn	P	S	Cr	Ni	N	Fe
%	0.025	0.47	1.67	0.035	0.027	18.35	9.40	0.095	bal

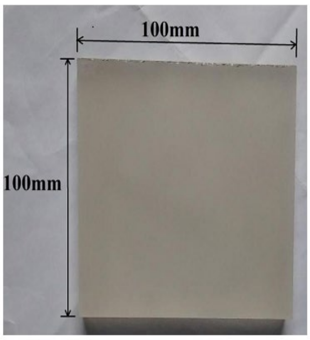


Fig. 1: Top view of the plate

Fig. 2: Front view of the plate

To optimize the input data during machining, a series of experiments are carried out on VMC. The two important machining parameters considered are cutting speed and feed rate in this experiment which affect the quality of circular pocket milled. Three levels viz. low (1), medium (2) and high (3) of the parameters are selected for experimentation. The range of machining conditions selected is based on the range suggested by the cutting tool manufacturer and previous literature review. Table 2 exhibits the ranges of the parameters selected according to Taguchi's L9 orthogonal array[24] to accomplish the experiments. To ensure the achieved results, each and every experiment is conducted twice and averages of these two results are taken.

Table 2. Ranges of Input parameters

Factors	Coded factors	Low (1)	Medium (2)	High (3)
Spindle Speed (RPM)	A	900	1200	1500
Feed rate (mm/min)	B	100	200	300

The performance characteristics required for the present study are cylindricity and perpendicularity. Figure 3 shows the actual workpiece after machining.

Fig. 3: Milled holes following layout with repetition on the workpiece

3. Results and discussion

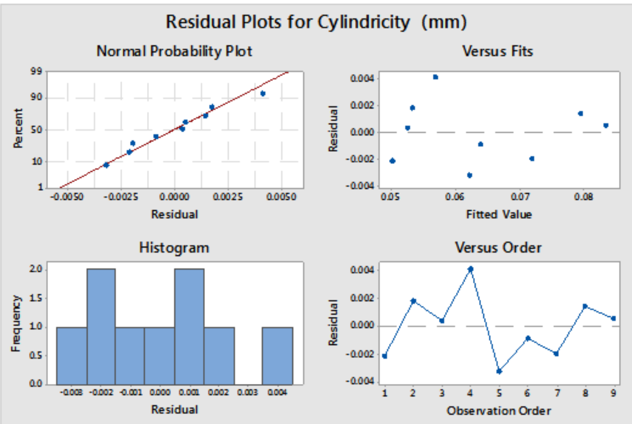
3.1 Cylindricity

Using analysis of variance (ANOVA) the adequacy of the model is ascertained. Regression equation corresponding to each response is determined using values of input parameters. ANOVA result of fitting a second order response surface model is shown in Table 3[25-30]. Higher the value of determination coefficient (R^2), better the model fits the observed data. The value of the coefficient (R^2 =0.9653) implies that 96% of variability of the response variable (cylindricity) can be explained by independent variables. Thus ANOVA serves as the foundation for model optimization. Highest 'F' value and correspondingly lowest 'P' value of independent variable A shows its significant relationship with cylindricity.

Table 3. ANOVA results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.001175	96.53%	0.001175	0.000235	16.78	.021
Linear	2	0.001114	91.47%	0.001114	0.000557	39.78	.007
A	1	0.001040	85.43%	0.001040	0.001040	74.28	.003
B	1	0.000073	6.04%	0.000074	0.000074	5.28	.106
Square	2	0.000041	3.40%	0.000041	0.000021	1.5	.358
A*A	1	0.000035	2.85%	0.000035	0.000035	2.5	.214
B*B	1	0.000007	0.55%	0.000007	0.000007	0.5	.539
2-Way Interaction	1	0.000020	1.66%	0.000020	0.000020	1.43	.316
A*B	1	000020	1.66%	0.000020	0.000020	1.43	.316
Error	3	0.000042	3.47%	0.000042	0.000014		
Total	8	0.001218	100%				

The residuals for cylindricity are plotted on a straight line in the normal probability plot which is displayed in Fig.4. It indicates that the residuals are distributed regularly. Also random order of residual values with respect to fitted values proves the regression model's suitability.



Model Summary

S	R-sq	R-sq(adjusted)	PRESS	R-sq(predicted)
0. 0037503	96.53%	90.76%	0. 0004034	66.87%

Fig. 4: Residual plots for Cylindricity

The main effect plot for cylindricity is shown in Fig. 5. It can be seen that, corresponding significant machining parameters settings are A3B3. The consequence shows that spindle speed (1500 RPM) and feed rate (300 mm/min).

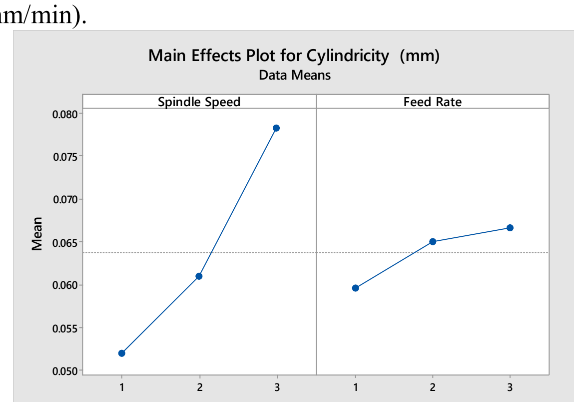


Fig. 5: Main effect plot for cylindricity

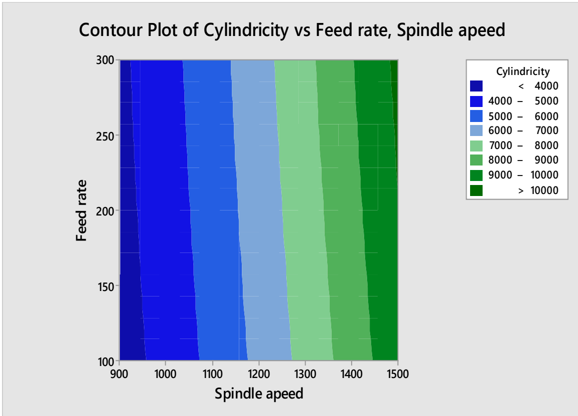


Fig. 6: Contour plot of cylindricity

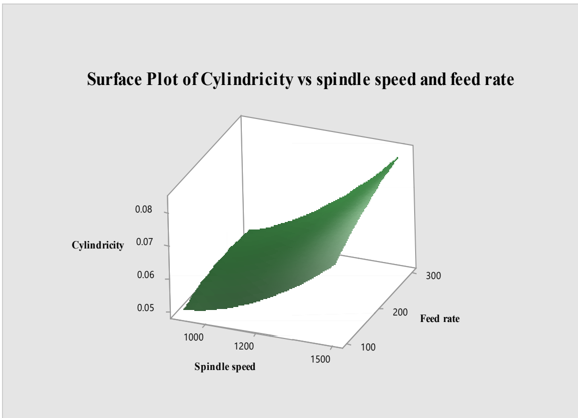


Fig. 7: Surface plot of cylindricity

Fig.6 shows a contour based interaction analysis between the spindle speed and feed rate. Increasing values of both spindle speed and feed rate result in increasing value of individual desirability for cylindricity as observed from the surface plot.

3.2 Perpendicularity

Table 4 shows the ANOVA analysis for perpendicularity. The value of R^2 is 93% which proves the suitability of the chosen model and again parameter A shows its significance with highest F value and lowest P value.

Table 4. ANOVA results

Source	DF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Model	5	0. 003051	93.15%	0. 003051	0.000610	8.16	.021
Linear	2	0. 002786	85.04%	0. 002786	0.001393	18.62	.007
A	1	0. 002604	79.50%	0. 002604	0.002604	34.81	.003
B	1	0. 000182	5.54%	0. 000182	0.000182	2.43	.106
Square	2	0. 000121	3.71%	0.000121	0.000061	0.81	.358
A*A	1	0. 000068	2.08%	0.000068	0.000068	0.90	.214
B*B	1	0. 000053	1.63%	0.000053	0.000053	0.71	.539
2-Way Interaction	1	0. 000144	4.40%	0.000144	0.000144	1.92	.316
A*B	1	0.000144	4.40%	0.000144	0.000144	1.92	.316
Error	3	0. 000224	6.85%	0.000224	0.000075		
Total	8	0. 003276	100%				

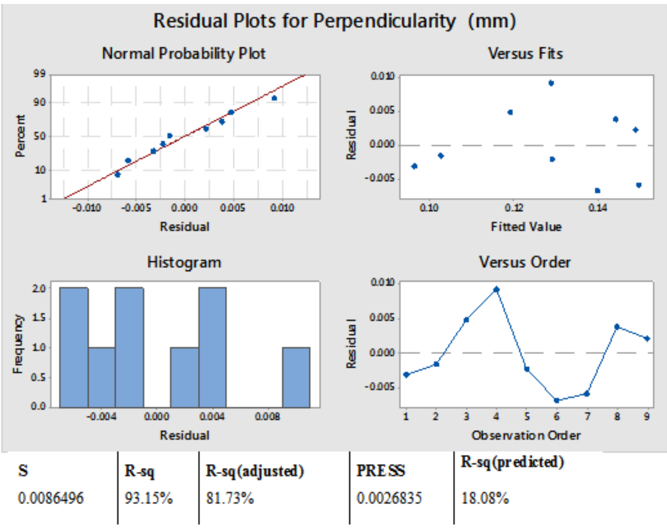


Fig. 8: Residual Plots for perpendicularity

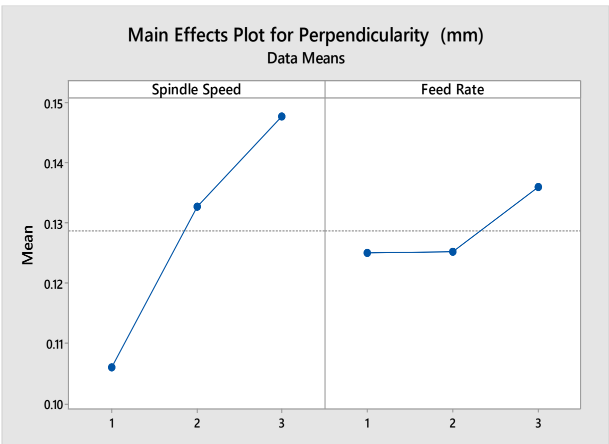


Fig. 9: Main effects plot for perpendicularity

The main effect plot for perpendicularity is shown in Fig. 9. It can be seen that, corresponding significant machining parameters settings are A3B3. The consequence shows that spindle speed (1500 RPM) and feed rate (300 mm/min).

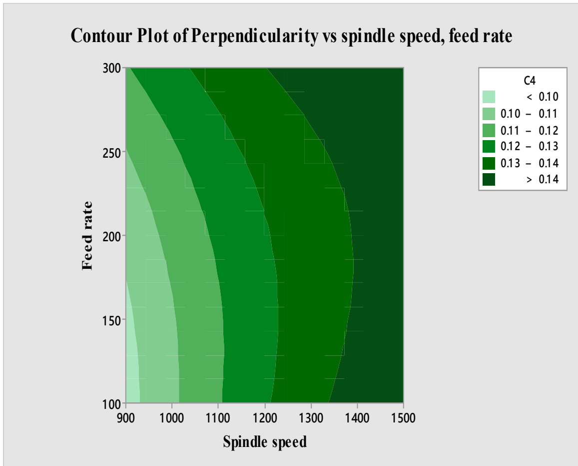


Fig. 10: Contour plot of perpendicularity

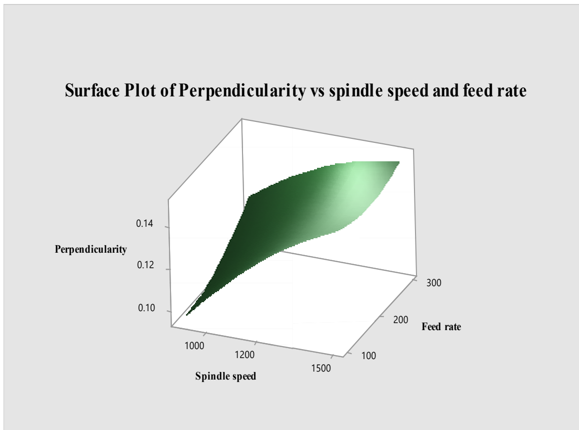


Fig. 11: Surface plot of perpendicularity

Figure 10 and 11 show the contour plot and surface plot for perpendicularity respectively. Increasing values of both spindle speed and feed rate result in increasing value of individual desirability for perpendicularity as observed from the surface plot.

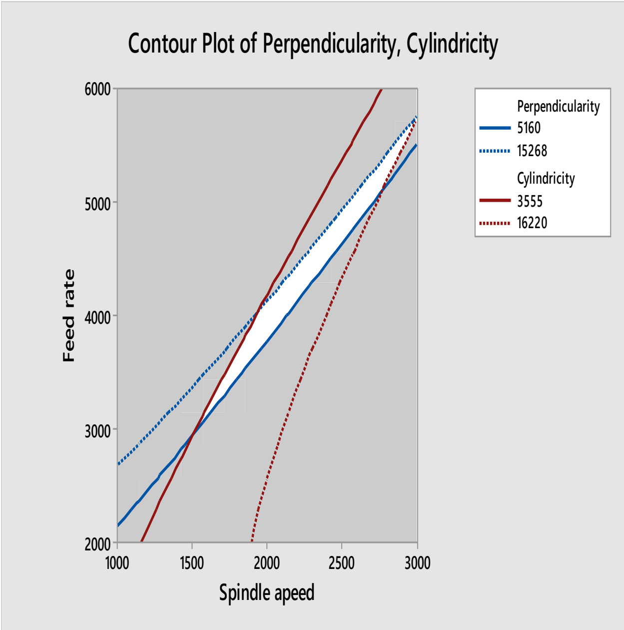


Fig. 12: Contour plots of perpendicularity and cylindricity

3.3 Optimization using desirability function

The desirability function is taken help for the parametric optimization. Optimization aims at obtaining the best combination of the operating parameters that has the maximum influence on the perpendicularity and circularity. The optimal solution of the criteria is presented in Figure 13. According to the criteria, the optimal parameters evaluated are spindle speed of 900 RPM and feed rate of 100 mm/min. The combination of input parameters giving highest desirability value is taken as optimum. In this study the maximum desirability value 0.94 is obtained.

4. Conclusion and Future Scope

This work analyzed the significance of milling parameters on cylindricity and perpendicularity of circular pockets in CNC milling operation. The experimental results and conclusions are as follows:

- Regression equation has been successfully used to develop the mathematical models for cylindricity and perpendicularity.
- ANOVA is used to determine the most important process parameters. The results reveal spindle peed is most significant process parameter.
- The achieved mathematical model exhibits the good combination of parameters.
- According to the desirability analysis, optimal parameters determined are spindle speed of 900 RPM and feed rate of 100 mm/min.

This work can be extended by considering some other performance criteria like roundness and also relevant input process parameters such as depth of cut, different materials, coolant etc.

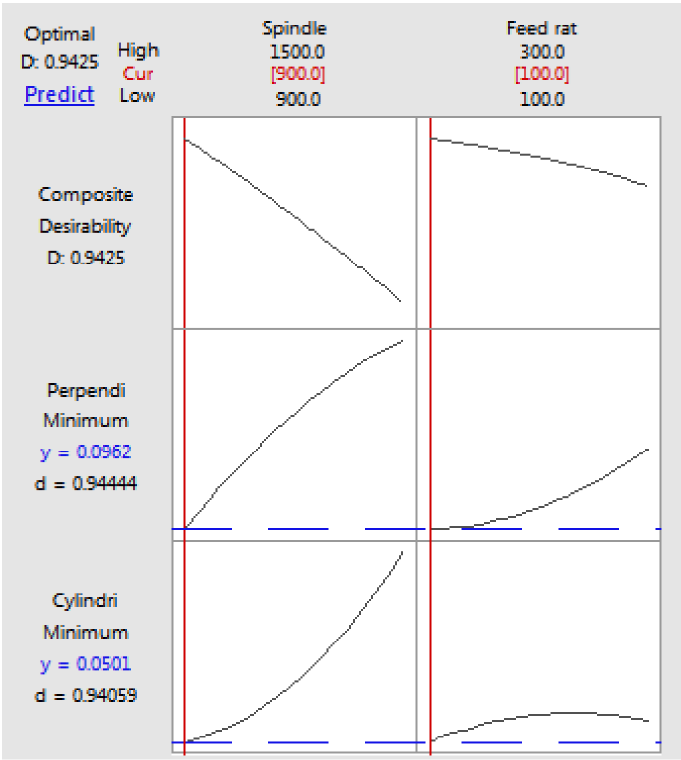


Fig. 13: Desirability analysis

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